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**Empirical Analyses of Human-Machine Interactions  
focusing on Driver and Advanced Driver Assistance  
Systems**

**2014**

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**Kyoto University**

**Empirical Analyses of Human-Machine Interactions  
focusing on Driver and Advanced Driver Assistance  
Systems**

By

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Dissertation submitted in partial fulfilment of the requirements for the  
Degree of Doctor of Engineering in the

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*To all my loved ones who encouraged me to reach this stage. I would also like to dedicate this work especially to the most important person of my life, my loving Grandmother.*



## Abstract

In the recent years automation has also made its way into the automobile industry. The driving operations are being assisted/ replaced by low to high level automated systems, called as Advanced Driver Assistance Systems (ADAS). The systems are devised to augment driver's situation awareness (SA) and road safety. ADAS are adept at what they are designed for. Nevertheless it is the '*robust interaction*' between the driver and the artifact which is essential to accomplish the fundamental objectives of this advanced technology. The prolific interaction in turn necessitates a '*functional mental model*' of the driver about the systems.

In safety critical tasks, operators are trained to help them nurture functional mental models of their interaction with automation. However, in automobile domain, there is no training of drivers to enable them foster functional mental models of the new technology from the commencement. The detailed information about the conditions is, no doubt, always provided in vehicle's manual, e.g., speed/brake thresholds, weather conditions, road segments' shape etc., beyond which the systems cannot function properly or work at all. But, it is likely that many drivers start interacting with the technology without having gained detailed knowledge by reading user manuals. Accordingly, drivers typically construct prejudiced mental models about the interaction and the assisting capacities of the system. The absence of vigorous training tools for drivers to get acquainted with ADAS, spurred us to investigate;

- The efficacy of users' experience based learning of ADAS.
- The implications of biased mental models upon drivers' situation awareness, i.e., awareness on both surrounding environment (aided/unaided by the system) and automation, and safe interaction.

For the purpose an experimental study was conducted using a driving simulator. A Lane Departure Warning (LDW) System with particular operational boundaries was employed as a test bed assistance system to be learned by naïve users. The content of drivers' mental models about the new technology was measured by multiple methods. The findings not only confirmed the naivety of users' mental models, but also revealed that the models did not evolve over the course for a considerable number of drivers. Drivers remained stick to their own interpretation of the system, even though they intermittently experienced the



situations which were beyond its operational capacities, e.g., crossed/touched the lane markings below the system speed threshold. The prejudiced mental model of the system impeded their observability causing complacency. Consequently, it inhibited the selection of appropriate decisions and actions and ultimately reduced safety.

The clear negation of the aforementioned queries led us to affirm that;

- Compared with other safety critical domains, no doubt, the sophistication of automation in automobile is far less, but the impacts of naivety and partiality of users' mental models are equally unsafe and undesirable for the interaction.
- If the problems of non-functional mental models of other realms are not to be replicated here, ADAS entails its conceptual illustration and timely education of drivers.

Thus, the presented work also documents our attempt to explore that whether driver's prospects can be reformed using different instructional techniques or the formal training procedures are the only solution. An *on-board quick guidance* on operational limitations of the LDW system through *visual display* as a candidate learning tool had been assessed. The encouraging results assured the contribution of the proposed methodology towards 1) drivers' mental model construction regarding new interaction with ADAS, 2) attaining intended situation awareness and safety.

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# 1. Introduction

## 1.1 Background

Since the time the human being has been interpreting the world around him, he has delineated the things by their spatial or temporal boundaries to better understand them. The paradigms which evolve through this practice facilitate his work by enabling him to frame qualitatively and quantitatively the different attributes of nature. They help him to transform the resources optimally to meet the objective. *Systems*, physical/non-physical, owe their origin to these paradigms. They are eventually employed to realize products that can serve humanity in the execution of any individual or collective purpose.

In the design of technical systems, figuring out the efficient ways of undertaking a task to achieve high performance, accuracy, reliability, to reduce cost etc., have always remained among main objectives. Furthermore the motivation to make more and new tasks possible has brought widespread use of tools and machinery in almost every single sphere of life. As technical systems advance, they get complex and it often necessitates the presence of *automation*, i.e., another controlling mechanism that can accomplish, fully or partially, but more proficiently a function that was or could be performed by a human (Parasuraman et al., 2000). The intention is no doubt to augment human sensory and cognitive abilities to attain goals competently and with less effort, and to mitigate the impact of variation in human performance. However, no such fully autonomous system has been realized yet which is capable enough to exclude the human intervention totally. The involvement of the human operator always stays there in some shape and size.

Not a very long time ago it had been realized that the *design of automations* was rarely accommodating the human operator/user and hardly taking account of his needs and characteristics. The designs were usually driven by technical requirements, which dampen its original purpose of extending the abilities of the operator. It did not facilitate them in understanding the functional aspects and capacities of the technology which increased the risk of human error. Due to the assumption that the design engineers themselves were human so the viewpoints of the user would naturally have been considered made the designers overlooked user's constraints (Sheridan and Parasuraman, 2005). These issues led to the exhaustive discussion on *human factors* and its applications to the designs of automation. Human factors research urged the design engineers to consider machine, control mechanism and human operator as entities of one main system rather than splitting them up into individual systems carrying out individual activities. It insisted that the designers should not only design physical relations *among things* but the relations *between people and things*. It was acknowledged that the modern human-automation systems require explicit engineering which meant, "fitting the user to the machine not only in terms of body, size and strength but also with respect to limits of vision, hearing, experience and learning capability" (Sheridan, 2002). Since then it has been fully appreciated that the robust interaction between the human and automation can only fulfil the essential functional purposes of the systems.

Thus with the rapid growth of technology, there is being a concerted effort to ensure rich collaboration between human and automation. Vital research is being carried out across the globe to provide standardization structure to address the issues related to the introduction of automation. *User's mental models* about the automation have been recognized to hold central position for the vigorous interaction. Substantial work is being done on optimizing interface designs to support the development of user's functional mental models. Computer based modeling and simulation tools are being utilized to evaluate candidate interfaces. It condenses time consumption and replaces high cost experimental events while keeping the reliability of the results decidedly sensitive to the quality of the design under consideration and the data originating from the real scenarios. Since experience based learning is not waited and counted on especially in safety critical tasks such as aviation, power plants, marine, process industries etc., the rigorous revisions of the training programs and instructional aids are also being realized to provide user/operators the conceptual bases to cultivate functional mental models of the behavior

of the system from the very beginning. Timely understanding of the coordination requisites and automation capacities that are likely to be misperceived by users, strengthen the interaction with well-designed interfaces.

## 1.2 Human-Automation systems in Automobile

Over the past decade or more the significant struggle has been made to incorporate smart systems and automation in the vehicles. *Driver inattention*, which has been frequently revealed as a major contributor to inner city and highway crashes in investigations, proved to be the main thrust for this introduction. In consequence, **Advanced Driver Assistance Systems (ADAS)** have been devised with an aim to reinforce driving operations, especially in the context of *situation awareness (SA)* (Endsley, 1988) and safety, and are getting increasingly popular. They are adept at detecting changes in vehicle behavior and the surrounding environment, and respond promptly. These technology-based support systems balance the influence of fluctuations in human driver performance, and supplement safety under normal as well as time-critical situations (Inagaki, 2008). Decreasing driver workload and improving traffic efficiency are also the goals of the technology. The most common ADAS in current automobiles are Lane Departure Warning (LDW) system / Lane Keeping Assistance (LKA) system, Blind Spot Warning (BSW) system, Distance Control Assist (DCA) / Forward Collision Warning (FCW) system and Full speed range Adaptive Cruise Control (ACC) system with Brake control. To all intents and purposes, ADAS is a sound and needed attempt towards safe driving. However, the introduction of automation in automobile domain, which is also a highly vulnerable realm, does not accompany any vital instructional aids besides improved interfaces. There is no training of drivers to enable them construct and develop functional mental models of their interaction with the new technology from the commencement.

### 1.2.1 Problem Synopsis

Like the people they are designed to assist, *ADAS have certain limitations, as speed/distance thresholds, weather conditions, road segments' shape etc.*, beyond which they cannot function properly or work at all. From a technical point of view, such operational margins are obvious in any system. However, the driving domain holds a tremendous variety of users where the working conditions of a given system may be totally unexpected or not easily perceivable by a common driver. Of course, the details of the

working boundaries of the systems are always well documented in the owner's manual, but it is likely that most drivers start interacting with the technology without going through the manuals at all. The clues through interfaces inside the vehicle may also be elusive if one has not read the manual. Accordingly, a common driver has a considerable tendency to construct over-generalized or prejudiced mental models of the working of the technology based on his/her own expectations, understanding and experience. The partial information acquired, for example, through advertisements, sales people or other people also hold a share in their mental models. Thus, there exists a high possibility of substantial gaps between the actual working scheme and the driver's mental model of the assistance system. The unpredictability of the time consumed by a driver to improve his/her mental models through learning from experience can put interaction with systems at continuous risk. These factors are indeed a devastating threat to safety.

Within their set boundaries, ADAS are significantly conducive to making drivers aware of the events and to assist them respectively, but the driver's attentiveness to the working margins of the system remains doubtful. If a driver starts using the system and his/her own mental interpretation of its operation does not functionally match the target system's behavior, then there prevail high chances of impairment of all levels of *situation awareness (SA)*, including automation awareness and judgments. The incomplete user's mental model of the system and limited information of the events that trigger state fluxes, can lead to role loopholes and behavioral changes which precinct the observability, hence causing complacency. This chain of incidents does not stop here; it further weakens the decision making, inhibits the execution of appropriate actions and ultimately reduces safety.

Thus, in order to achieve real safety with ADAS, with the users who are from diverse backgrounds; who might have not read the manuals thoroughly; and who are not trained on systems, *it is required to develop the methods and means to help them foster functional mental models about the system and its capacities from the very beginning*. It is because that these are their mental perceptions and understanding which could completely preclude the benefits and the whole purpose of ADAS.

ADAS design principles and implications are being explored extensively around the globe. However, to the best of our knowledge, the analysis of the response of ingenuous users of ADAS, under the influence of their impaired or prejudiced mental models about it, has received little attention until now. The implications of drivers'

prejudiced mental models in this interaction and their natural trends towards apprehending the operational satisficing conditions of the systems have not been investigated in depth.

### 1.3 Research Aims and Objectives

On the basis of the aforementioned concerns, the scope of this research is

- To study the existing advanced driver assisting technologies in the commercial automobiles; especially focusing on their capacities and functional limitations, and the way the system(s) presents the information to the drivers through interfaces.
- To assess if experience based learning be waited and counted on in this particular safety critical task. If a driver starts using ADAS with only minimal knowledge and his/her prejudiced mental model lacks essential aspects of the working criteria of the systems, can he/she nevertheless recognize and correct errors in their model using only their driving experience, without any kind of explicit feedback.
- To verify whether information about the operational boundaries of the system should be confined to user manuals only and let the drivers learn on their own, or these smart technologies call for clear elaboration/training for attaining genuine safety.
- If training is proved to be required, then to evaluate whether employing in-vehicle quick but comprehensive guidance via visual/verbal displays for modification of driver's prospects in terms of capacities and limits of a system could be a candidate solution or the "formal training/education" is the only option.
- To evaluate the role of an Event-Driven Prompted Display about the out-of-capacity state of the system in user's learnability and memorability.

Hence this project focuses upon how to improve the overall driver-automation system performance in dynamic driving environments. PreScan® software would be utilized for ADAS simulation in this research.

### 1.4 Dissertation Outline

The dissertation consists of six chapters.

Chapter 1 includes a brief overview of the requisites of human-automation interaction, and the methods to help users develop functional mental models of it, e.g., improved interfaces and training aids. It summarizes Advanced Driver Assistance Systems,



an example of human-automation systems in automobile domain, and a potential problem associated with it. Chapter also describes the need and objectives of the research and the outline of dissertation.

Chapter 2 covers the literature review of human-automation interaction. Two main topics are reviewed in this chapter, i.e., automation and levels of automation; and human factors. The detailed discussion on classes of human behaviors, the term situation awareness and mental models has also been carried out.

Chapter 3 relates to the critical review of Advanced Driver Assistance Systems (ADAS). Categories of ADAS, needs and their expected benefits have been gone through. It also provides the overview of human factors associated with driving automation; developed ADAS design principles and concerns regarding training of drivers on systems.

Chapter 4 covers the empirical study carried out to investigate the development of driver's mental model of a Lane Departure warning System while driving. It also describes the methodology and experimental setup for verifying the objectives and purposes of the study. Appendices are provided to support the description.

Chapter 5 includes the experimental study to evaluate an on-board visual display for quick guidance on operational limitations of the LDW system as a candidate learning tool for naïve drivers. Experimental set up and related appendices have been provided for elaboration.

Finally, Chapter 6 summarizes the whole work of doctoral dissertation by discussing the conclusions and recommendations for future work

## 2. Human-Automation Interaction

### 2.1 Automation

*Automation* is traditionally known as a machine which works on its own by means of a control system. The term automation, inspired by the former word *automatic*; which found its derivation from *automaton*, was not widely in use before 1947 (Rifkin, 1995). The first use of the term is traceable to a 1952 article by Scientific American magazine (Sheridan, 2002). It was during this time that industry was growing and expeditiously adopting the feedback controllers, which were introduced back in 1930s (Bennett, 1993). The description of the term has undergone several modifications over the years. For example, the context of the original usage of the term was manufacturing. When its application went beyond manufacturing industry, it started getting explained as the introduction of automatic control to any branch of industry or science.

In the domain of human-machine systems, e.g., aircraft and air traffic control, automobile, trains, ships, spacecraft, teleoperators, power plants, hospital systems, etc.; automation is the exploitation of artifacts to replace human labor, where labor could be either physical or mental, and to make task performance more efficacious. According to Sheridan (Sheridan, 2002), “*automation refers to (i) the mechanization and integration of the sensing of environmental variables by artificial sensors; (ii) data processing and decision making by computers and (iii) mechanical action by devices or information action by communication of processed information to people*”. It can attribute to closed-loop control or open-loop operation on the environment. Automation is thereby a technological

replication of human's perception-action cycle (Neisser, 1976), wherein humans perceive through their senses; analyze acquired information and make decisions through cognitive functions and act using their limbs. Automation to varying extent can perform all the functions in the perception-action cycle (Parasuraman et al., 2000). Automation can be realized utilizing various means including mechanical, hydraulic, electrical, pneumatic, electronic devices and computers usually in combination. The history of automation encompasses the substantial engineering developments of the aforementioned devices and all the associated physical systems.

### 2.1.1 Levels of Automation

Automation can be employed in both simple and complex artifacts to extend human abilities to attain goals. In simple artifacts, the understanding of how to reach the intended goal and the control of how the action should be implemented lies to a great extent within the human's perceptual-motor skills. As artifacts become advanced or more complex; they take over a larger part of the control during the performance of a task. These artifacts together form a technical system, which is governed by a control system, which in turn is supervised by a human operator (Andersson, 2010). Since tasks are performed jointly by humans and machines together in human-automation system, the levels of automation had been contrived for the purpose.

The phrase *level of automation (LOA)* has been defined by Frohm (Frohm et al., 2008) as “*the allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging between totally manual and totally automatic*”. Thomas B. Sheridan along with his colleagues has done an exhaustive work on the levels of automation continuum (Sheridan and Verplank, 1978; Parasuraman et al., 2000; Sheridan, 1997; Sheridan, 2011). They proposed a model for types and levels of automation. They adopted a simple four-stage scheme of human's perception-action cycle for categorization of automation, shown in Fig. 2.1, as it has its equivalent in system functions.

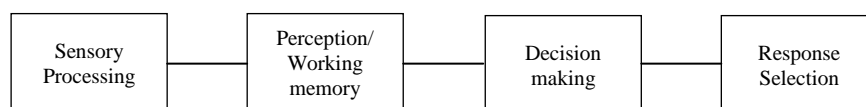


Figure 2.1: Four-stage model of human information processing (Parasuraman et al., 2000)

They accordingly referred to the four types as:

- Acquisition automation

- Analysis automation
- Decision automation
- Action automation

The automation of information acquisition embodies the sensing and record-keeping of input data whereas automation of information analysis comprises inferring process and logical reasoning. Analysis automation integrates information which serves the purpose of augmenting human operator's perception and cognition. Decision automation governs decision and action selection from among several alternatives to prescribe a specific decision choice if particular conditions are satisfied. In this case systems are designed with conditional logics. Automation of the fourth and final stage, i.e., action implementation, involves machine execution of the choice of action in a contextually appropriate manner (Sheridan, 2002; Sheridan and Parasuraman, 2005; Parasuraman et al., 2000).

It has been discussed in detail in their research work that in a particular system all four dimensions can be automated to differing degrees or many levels. They suggested a 10-point scale model for levels of automation of these functions, as illustrated in Table 2.1 and Table 2.2.

<b>Automation of Information Acquisition and Integration</b>	
<b>Level</b>	<b>Description</b>
<b>1</b>	The computer offers no assistance: the human must get all information
<b>2</b>	The computer suggests many sources of information, or
<b>3</b>	Narrows the sources to a few, or
<b>4</b>	Guides the human to a particular information, and
<b>5</b>	Responds to questions posed in restricted syntax, or
<b>6</b>	Responds to questions posed without restricted syntax, and
<b>7</b>	Integrates the information into a coherent presentation, or
<b>8</b>	Integrates the information into a coherent presentation, with indication of confidence about each aspect, and
<b>9</b>	Passes it to human or automation for action, but allows for other consideration
<b>10</b>	The computer collects information as it sees fit, packages it, and presents it to human or automation for action with no opportunities to consider alternatives.

Table 2.1: Levels of Automation of Information Acquisition and Integration (from Sheridan and Verplank, 1978; Sheridan, 1997)

In the model the higher levels are representing increased autonomy of automation over human activities. It implied that automation is not all or none, however it can vary from the highest level of full automation to the lowest level of fully manual performance.

<b>Automation of Decision and Action selection</b>	
<b>Level</b>	<b>Description</b>
<b>1</b>	The computer offers no assistance: the human must take all decisions and actions
<b>2</b>	The computer offers a complete set of decision/action alternatives, or
<b>3</b>	Narrows the selection down to a few, or
<b>4</b>	Suggests one alternative, and
<b>5</b>	Executes that suggestion if the human approves, or
<b>6</b>	Allows the human a restricted time to veto before automatic execution, or
<b>7</b>	Executes automatically, then necessarily informs the human, and
<b>8</b>	Informs the human only if asked
<b>9</b>	Informs the human only if, the computer decides to
<b>10</b>	The computer decides everything and acts autonomously, ignoring the human

Table 2.2: Levels of Automation of Decision and Action selection (from Parasuraman et al., 2000)

Hierarchy of levels of automation had also been developed by Endsley and Kaber to have pertinence to the performance of dynamic cognitive and psychomotor control tasks in various domains including aircraft piloting, teleoperators, air traffic control, etc. (Endsley, 1999). They identified four generic dimensions intrinsic to these domains, which were:

- Monitoring
- Generating
- Selecting
- Implementing

Monitoring function refers to the scanning of the system displays to perceive information and its status. Developing strategies and framing options to realize objectives and goals come under generating dimension. Selecting implies the decision activity for a particular

option or scheme and implementing function denotes execution of chosen choices. The levels listed in the taxonomy, illustrated in Table 2.3, represent a range of feasible assignments of the aforementioned four functions to human, computer and human/computer combinations.

Level of automation		Roles			
		Monitoring	Generating	Selecting	Implementing
1	Manual control (MC)	Human	Human	Human	Human
2	Action support (AS)	Human/Computer	Human	Human	Human/Computer
3	Batch processing (BP)	Human/Computer	Human	Human	Computer
4	Shared control (SC)	Human/Computer	Human/Computer	Human	Human/Computer
5	Decision support (DS)	Human/Computer	Human/Computer	Human	Computer
6	Blended decision making (BDM)	Human/Computer	Human/Computer	Human/Computer	Computer
7	Rigid system (RS)	Human/Computer	Computer	Human	Computer
8	Automated decision making (ADM)	Human/Computer	Human/Computer	Computer	Computer
9	Supervisory control (SC)	Human/Computer	Computer	Computer	Computer
10	Full automation (FA)	Computer	Computer	Computer	Computer

Table 2.3: Levels of Automation for dynamic-cognitive and psychomotor control task performance

(from Endsley, 1999)

Some other researchers (Ntuen and Park, 1988; Save and Feuerberg, 2012) have also developed hierarchies of levels of automation for the domains like teleoperated systems and air traffic management, etc., but Sheridan and Verplank's model for levels of automation has served as the foundation for the whole work in this realm.

## 2.2 Human Factors

Technological revolution in computer hardware and software has realized the introduction of automation into virtually all aspects of human-machine systems (Sheridan and Parasuraman, 2005). Sophisticated automation has become ubiquitous, appearing everywhere in work environments (Lee and See, 2004). The use of automation in complex socio-technical systems has ascertained unprecedented reliability, improved productivity and economy, reduced workload and fewer errors (Jamieson and Vicente, 2005). Nevertheless, the absence of human factors consideration in the design of automation has evidenced that even technologically state-of-the-art systems become perplexing than beneficial. It is because that automation does not merely supersede human activity but rather changes it and often imposes unintended or unanticipated coordination demands on

the human operator (Parasuraman and Riley, 1997).

*“Human factors, also known as human engineering or human factors engineering, is the application of behavioral and biological sciences to the design of machines and human-machine systems”*. The behavioral sciences are cognitive psychology which includes sensation, perception, memory, thinking, analysis as well as motor skills. Since the interaction of humans with automation deals more with sensory and cognitive functions, the term cognitive engineering therefore came into vogue (Sheridan, 2002). Cognitive engineering is the application of what is known from cognitive science to the design and construction of artifacts or machines (Norman, 1986).

### 2.2.1 Automation usability problems

In the design of the systems, human factors take the perspective of the human operator/user. The notion started gaining attention slowly in the 1930s and 1940s, but soon after attained speed and momentum. The driving force was the growing complexity of socio-technical systems, which resulted in the automation usability problems related to the new roles of the operators and failures to cope with them, for example:

- **Clumsy automation:** It is defined as poorly designed automation which makes easy task easier and hard tasks harder affecting workload distribution (Wiener, 1989).
- **Situation awareness:** It is “ *the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future*” (Endsley, 1988). Automation often makes the operator a *passive* observer of the system rather than *active* controller and permits him to allocate his attention elsewhere than the system. It reduces situation awareness where the operator does not know what has happened in the past, holds a poor understanding of the ongoing series of events and is unable to decide and plan what to do next (Endsley, 2012).
- **Skill degradation:** Loss of skill can be referred to as the deterioration of manual and cognitive skills and impairment of operator’s knowledge structure due to the continuous usage of automatic controls (Sheridan and Parasuraman, 2005). There is a considerable body of research in cognitive psychology documenting that reduced opportunities to practice manual tasks and disuse of cognitive skills lead to forgetting and skill decay (Rose, 1989).
- **Trust in automation:** Trust or reliance on automation varies over continuous grades

rather than being a static binary state of either yes or no reliance. Over-reliance on automation or complacency is developed when the user/operator forms beliefs of the system as being more capable than it actually is (Lee, 2006). However, the operators can hold a skeptical view of the technology which can attribute to distrust and too little competency to the technical system (Parasuraman and Riley, 1997).

- **Out-of-the-loop performance:** The problem has been described as “*automatic system operator’s diminished ability to detect system state/errors and subsequently perform tasks manually in the face of automation failures*” (Endsley, 1995). Partial mental models which give rise to reduced situation awareness and complacency; and skill degradation collectively contribute to the out-of-the-loop performance problem.

These issues made human factors and in particular the apocryphal human error more conspicuous (Hollnagel and Woods, 2005). It was widely agreed that people/user cannot be thought about separately from the technology that is made to assist them. It is required that people and automation coordinate as a joint system, and work as a single team. Breakdowns in this coordination lead to disaster as the cognitive demands of the work domain cannot be met simply by adding the efforts of individual agents working in isolation (Christoffersen and Woods, 2002). The investigation regarding how automation affects human-machine system performance was primarily performed in the aviation domain, which then continued to have been considered in process control, shipping and medicine, etc.

Thus in this context efforts had been and are still being put in to provide insights into human behavior and cultivate methodologies on how to support the design of technology that augments human work, for example to name a few; (Fitts and Posner, 1967; Whitehead, 1985; Rasmussen, 1968; Rasmussen and Lind, 1981; Rasmussen, 1983; Wieringa and Stassen, 1999; Wei et al., 1998; Li and Wieringa, 2000; Johannsen, 1992; Johannsen et al., 1994; Miller and Parasuraman, 2007; Swain, 1990; Klien et al., 2004; Norman, 1990; Norman, 2007; Parasuraman et al., 2009; Parasuraman and Riley, 1997; Sheridan and Parasuraman, 2005; Hollnagel, 2012a; Hollnagel, 2012b; Donmez et al., 2008).

Substantial research work has also been done to analyze monitoring problems of automated systems and to make human-centered design to enhance operator’s situation awareness, for instance;



(Endsley, 1988; Endsley, 1995; Endsley, 2000; Endsley and Garland, 2000; Endsley and Robertson, 2000; Endsley, 2012; Kaber and Endsley, 2004; Adams et al., 1995; Gawron, 2008; Klein, 2000; Stanton et al., 2001). Remedies to address error tolerance, training issues and organizational factors have been searched in depth and are being proposed; few examples of the relevant work from the literature are as follows (Albert et al., 2000; Rasmussen and Vicente, 1989; Rouse and Morris, 1986b; Kraght and Landeweerd, 1974; Gaba et al., 1995; Salas et al., 1999; Moray et al., 1986; Salas and Cannon-Bowers, 2001; Beaubien and Baker, 2004).

In the perspective of human factors, the design of *user-centered* interfaces for automation had also gained huge attention and is still under great consideration, such as (Degani et al., 1999; Pawlak and Vicente, 1996; Vicente and Rasmussen, 1992; Bennett et al., 2001; Heymann and Degani, 2002; Heymann and Degani, 2007; Ming et al., 2011; Jamieson and Vicente, 2005; Miller and Parasuraman, 2007; Burns and Hajdukiewicz, 2013; Rasmussen and Vicente, 1990). To improve overall human-machine system performance it had been asserted that the work domain and its contextual factors on different levels of abstraction should be used as a basis for analysis (Vicente, 1999; Naikar et al., 2006; Naikar et al., 2003; Sanderson, 1998). For human-centered automation design, task analysis is being highly encouraged to define what variables in what ranges are important, what kind of people to consider, how well trained they are, what motivation they have, which system function should be automated and to what extent, etc., (Sheridan, 2011). Defining and describing the types and levels of automation are the outcome of the attempts in this regard as well.

The constituents of human factors literature which have been utilized in the presented work have been tried to go through briefly but concisely in the following sub sections. The notion of mental models in human-automation interaction holds a central place in our study so it has been introduced and discussed in a separate section.

### 2.2.2 Rasmussen's human behavior model

Rasmussen (Rasmussen, 1976; Rasmussen, 1983) presented the idea that human behavior can be classified into three typical levels of performance.

- **Skill-based behavior:** It represents human's sensory-motor performance during the activities or task execution, which occur as smooth, programmed and highly integrated patterns of behavior.

**Rule-based behavior:** In a familiar work situation, the performance of activity is typically controlled by stored schemata which might have been evolved empirically through former occasions, during communication with other people as guidance or instructions, or it can be formulated on spot by conscious planning and problem solving.

Rasmussen (1983) also narrated that the boundary between these two behaviors is to a certain extent not distinctive, and also depends on the degree of training the person has attained and the level of attention he/she is allocating. Skill-based performance prevails without the conscious control of human, and the person may not be able to describe how one controls and on what indicators or information the performance is based, while rule-based behavior tends to have explicit foundations and the person can report the rules used.

- **Knowledge- based behavior:** During unfamiliar situations, where no stored rules are assisting then performance is goal-controlled and knowledge based. On the basis of the analysis of the environment and overall objectives of the person, explicit goals are prepared. Plan is developed, functional properties of the environment are understood and predictions are made against plan's effects.

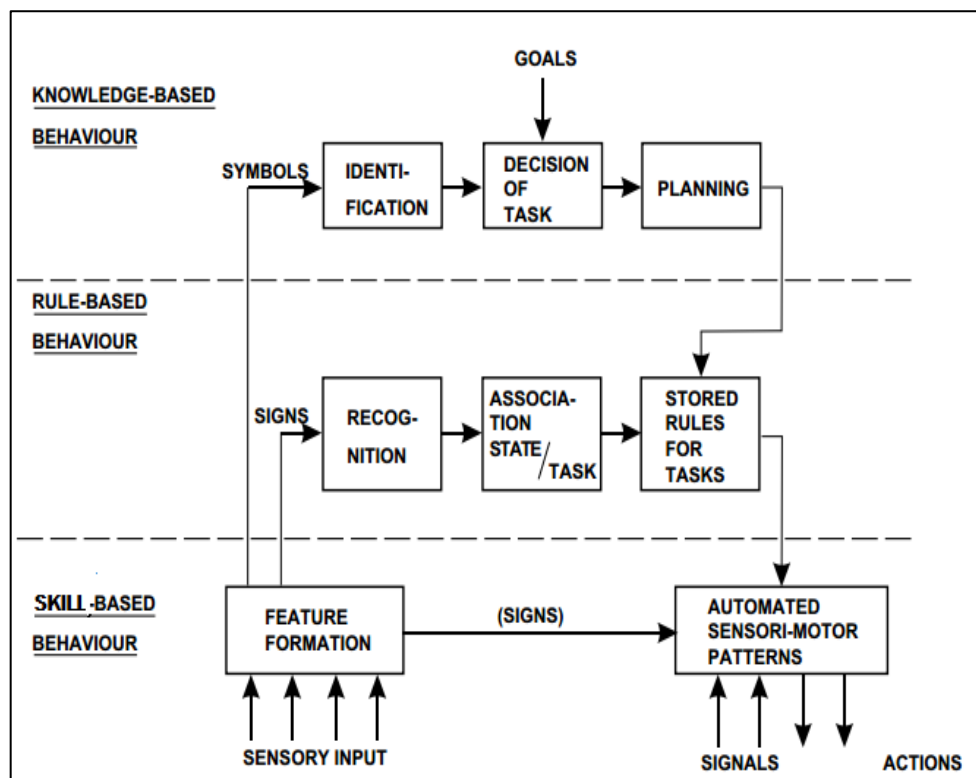


Figure 2.2: Three levels of skilled human operators' performance (from Rasmussen, 1983)

In his work, the author asserted that for the coordination of humans and automation in a joint system the single integrated quantitative model of human performance neither work nor needed, but rather an overall qualitative model is the requisite which allows the designers to match categories of performance to types of situations. To match the design of the system to human capabilities in a specific task, the information on the subjective human preferences or performance criteria that controls the selection of a strategy in a given situation is necessary. He deduced that in order to make the design of modern technology even more effective, the consideration of human performance in an integrated way than separate paradigms is a necessity.

### 2.2.3 Situation Awareness (SA)

The term situation awareness, originally used by the aircraft pilot community, has acquired a major attention and consideration in all those domains where people operate complex dynamic systems. The fields include, no doubt, military aviation, nuclear power plants, air traffic control, teleoperations, marine industry, maintenance and advanced manufacturing units, etc. Achieving situation awareness is central for operator's good decision making and performance; nonetheless it has always remained the most challenging aspect of the machine design and operator's job.

Endsley (Endsley, 1988) formally defined situation awareness as “ *the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future*”.

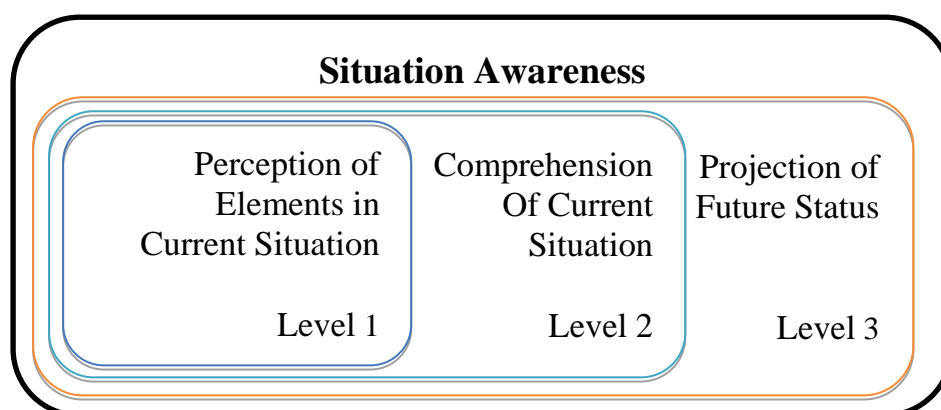


Figure 2.3: Model of Situation Awareness (SA) (from Endsley, 1988)

Situation awareness, as shown in Fig. 2.3, includes the perception of critical factors in the situation or environment which is Level 1 SA, then comes up the understanding of the meaning of those factors, especially when the goals of the person are integrated together

with them which constitutes Level 2 SA. At Level 3 SA, it is estimated that what can happen in the near future. The higher levels of situation awareness are critical for operators to take decisions which should be both prompt and effective (Endsley and Garland, 2000). She also proposed the model of situation awareness in dynamic decision making to demonstrate what “knowing what is going on” entails.

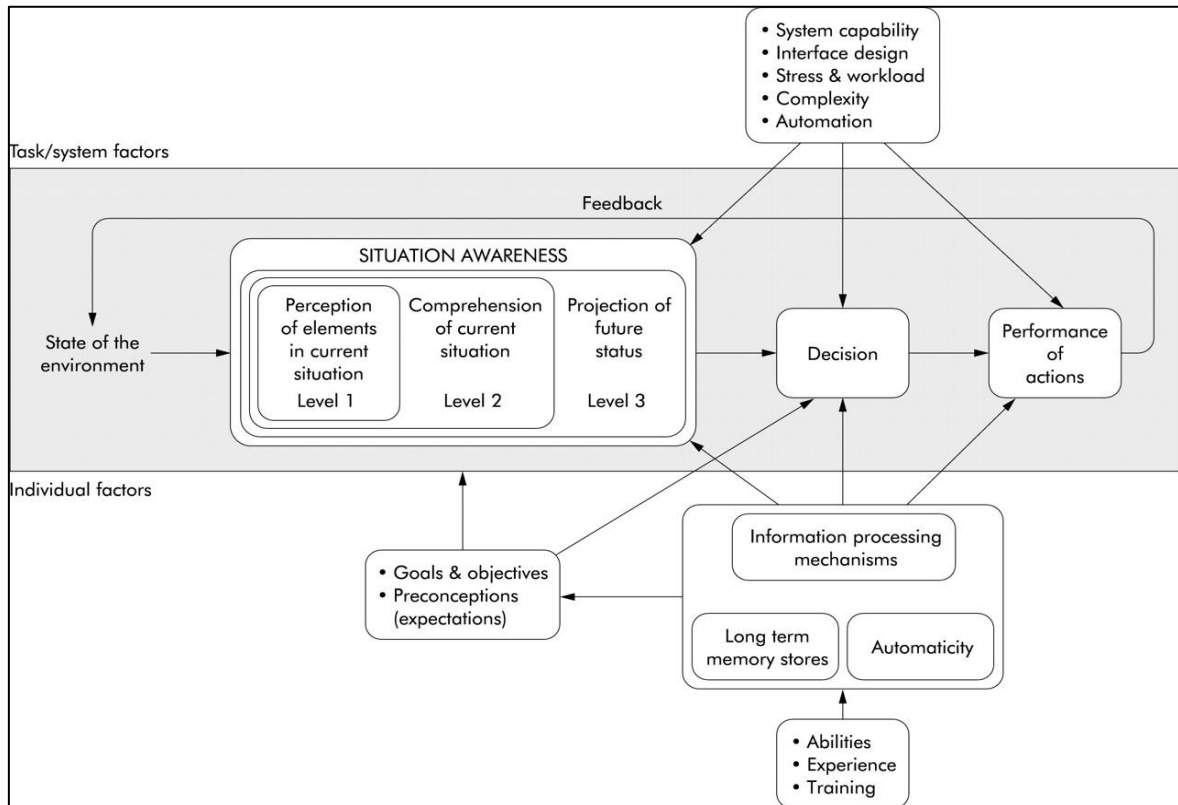


Figure 2.4. Model of SA in dynamic Decision Making (from Endsley, 1995)

The factors that affect situation awareness had been discussed in detail in their work because it is indeed a main precursor to decision making and performance and these distinct stages could affect each other in a circular ongoing cycle. System factors and individual factors had been identified, as indicated in Fig.2.4, to propose methodologies and remedies to address machine design and human operator issues. Endsley and her colleagues had suggested a good number of approaches for indirect and direct measurement of SA and instigated to evaluate design concepts (Endsley and Garland, 2000; Endsley, 2012).

In our work two direct measures of SA that have been utilized to get acquainted with user's situation awareness are

- Post-test questionnaire

- Situation Awareness Global Assessment technique (SAGAT)

Objective measures strive for assessing SA by comparing directly a person's reported SA to reality. Post-test questionnaire includes the asking of questions to the subject at the end of a simulated trial. However, in SAGAT operator-in-the-loop simulation exercises are conducted. At randomly chosen intervals, the simulation activity is halted for a short time, the displays are blanked and a set of questions are administered to the participant. Data collected by the simulation computer and by subject matter, the participant's responses are examined and evaluated based on what was actually happening in the scenario during that time (Endsley, 2012).

The method necessitates the appropriate timings for the queries, and appropriate content and context of the questions which is ensured by comparing to the provided guidelines.

## 2.3 Mental Models

Kenneth Craik was the first who introduced the term “mental models” in his book, of *The Nature of Explanation* (Craik, 1943). According to him mental models are ‘*small scale models of reality*’ which human beings use to reason, anticipate and explain events. These are internal representations of external objects or phenomena which consist of words, numbers or symbols. Gentner and Steven have defined mental models in their book titled *Mental Models* (Gentner and Stevens, 1983) as people's mental representation of domain knowledge which provides people the basis to make domain related inferences.

### 2.3.1 Mental models in Cognitive Psychology

The notion of mental models is a part of a continual theoretical development in attempts to explicate the human mind and human behavior (Zhang, 2010). In cognitive science or psychology, similar cognitive structures have been proposed to account for knowledge representation and human information processing which includes

- Schemata
- Scripts
- Frames

Schemata are postulated as building blocks of cognition and root elements upon which human perception, comprehension, learning, memory and problem solving depends

(Rumelhart, 1980). Scripts and frames represent data structures that had been proposed for computer simulation of human beings' intellectual activities. Script describes appropriate sequence of events in a particular context (Schank and Abelson, 1977). Frame embodies a stereotyped situation, attached to which are several kinds of information regarding action, planning, expectations, etc. It consists of network of nodes and relations (Minsky, 1974). In the literature no clear discriminatory lines have been drawn between the three concepts and it is agreed that the discussion of any of one of them will lead to the other. People assimilate new information into their existing schema or script or frame and adapt it to fit reality. When the existing schema or selected script or frame cannot fit the situation, new schemata can be created and scripts/frames can be replaced to accommodate the new information (Zhang, 2010). Most researchers believe that mental models are the utilization of schemata, scripts and frames in a computationally dynamic manner. Mental models are running mode of these data structures (Johnson-Laird, 1983; Norman and Bobrow, 1979; Rumelhart, 1980; Brehmer, 1987).

### 2.3.2 Mental models in human-machine interaction

In human-computer interaction and human-machine systems, it has been accepted that the term mental models refer to knowledge representation that user/operator employs to understand the system and to comprehend its functionality/operation (Norman, 1986; Norman, 2007; Brehmer, 1987; Sheridan, 2002; Moray, 1999). A widely recognized definition of mental model was suggested by Carroll and Olsen (Carroll et al., 1987) which was, *"the user's mental model of a system is a rich and elaborate structure, reflecting the user's understanding of what the system contains, how it works, and why it works that way. It can be conceived as knowledge about the system sufficient to permit the user to mentally try out actions before choosing one to execute"*. Thus mental model is both a knowledge structure and dynamic tool that empowers users to interact with a system.

DiSessa (Disessa, 1986) presented the concept of mental model in contextual specificity as consisting of

- **Structural Model:** It encompasses information related to the internal structure/mechanics of the device or system in terms of its components. There exists only one structural model for the system that is universally applicable.
- **Functional Model:** It includes information regarding the use of a selected set of functionality of a system to perform a specific task. These models are task related and

reflect the relationship and interdependence of goals and means.

Rasmussen developed taxonomy of mental models of a system which includes five types: physical form, physical function, functional structure, abstract function and functional purpose (Rasmussen, 1979; Rasmussen, 1986). On this bases, Rouse and Morris also narrated that operator's mental models could illustrate that why a system exists, i.e., system purpose, how a system operates, i.e., its function; what a system is doing, i.e., its state; and what a system looks like, i.e., its form (Rouse and Morris, 1986a). Norman has emphasized that in human-machine interaction the operator/user's mental model need not be structurally accurate but it has to be functional to correspond with the target system behavior (Norman, 1986; Norman, 2007).

### **2.3.3 Characteristics of mental models**

Mental models inherent incompleteness and owe their origin from fragmented knowledge which intrinsically is a set of loosely connected ideas. Mental models evolve and get updated and modified as individuals gain experience. They do not possess firm boundaries and people's mental models of one domain may have impacts on the construction of their mental models of another domain. Although runnability is a critical feature of mental models, human being's cognitive ability to construct and run a model is severely limited (Norman, 1986; Norman, 2002). There are generally three patterns for people to adapt to new system which are (Cool et al., 1996):

- Fitting new systems to old mental models
- Combining old and new mental models
- Constructing a new mental model of a new system through proper learning

People generally follow the first two patterns of adaptation. People have the tendency to speculate about the underlying mechanisms when using a system, based on their observation, understanding and preconceptions. It is very common for them to develop misconceptions about a system and is often difficult for them to come out of fallacies (Norman, 2007). If the system behaves as expected or inoffensively, the users would assume that their mental models are correct or valid. The users also tend to create causal relationships based on co-occurrence of events, even though the system's behavior might not have generated by the speculated mechanism (Zhang, 2010). It is well documented that during the operation of the system if an error occurs, operators often do not rationally explore the environment and accordingly update their mental models. Rather, they

persistently try to fix it by fitting data to their existing models and ignore that information which is not consistent with their expectations (Norman, 2002).

#### **2.3.4 Functional mental model building and development**

People construct and employ mental models to direct their interaction with systems (Carroll et al., 1987). They serve as a foundation for taking sensible actions during the interaction. User's behaviors result from intentions and that intentions are functions of attitudes which in turn based on beliefs governed by mental models (Lee and See, 2004). Users approach a particular system with different preconceptions and mental models. Since safety critical tasks, such as, aviation, marine, power plants etc., include sophisticated operation of and interaction with systems, it significantly requires adequate mental models construction and development of the operators about the domain.

The exploration of mental models and their types by the researchers has provided insights into the interplay of mental models in users' learning and performance. Novice users always have limited knowledge repository and repertoire of problem solving strategies. According to Norman (1986), the provision of conceptual model of the system can transform confusing, difficult tasks into simple straightforward ones. The discrepancy between psychological and physical variables creates the major issues, which if addressed through interface design of the system and training about it, could be overcome. Simply giving more information is not sufficient for improving performance, rather specific information about the system topology and functioning is essential to support direct inferences about the behavior of the system (Kieras and Bovair, 1984). Halasz and Moran have illustrated the effectiveness of providing users with a conceptual model of the system for enhancing their performance (Halasz and Moran, 1983).

*User-centered* interface designs and ecological interface designs, about which examples from literature have been mentioned earlier, use the idea of providing the conceptual model of the system to the user. It has also been stressed in literature that instructional aids and training programs should comprise features that are likely to be misperceived by users (Hanisch et al., 1991). Operators should be enabled to develop a mental model of the system that comprises knowledge both of its normal operating states and its failure states. In the case of normal operations, the model is a set of anticipations that what control actions can lead to what changes in associated variables, and when. In the case of abnormal operations, the necessary diagnostic model must contemplate the variety



of ways in which system could fail and must include the problem solving measures. Lack of knowledge is an important source of mistakes and it is not surprising that increased training can reduce their frequency (Hollands and Wickens, 1999).

Literature on *Naturalistic Decision Making (NDM)* and *Recognition-Primed Decision Making (RPDM)* (Lipshitz et al., 2001; Klein, 2008; Patterson et al., 2009) emphasizes that decision makers in natural settings use situated content-driven cognitive processes to solve domain-specific problems. Thus, training should incorporate pattern recognition and pattern matching as it enhances mental model driven cognitive processes which further augments operator situation awareness, reasoning and error recovery (Gaba et al., 1995; Salas and Cannon-Bowers, 2001; Salas et al., 1999).

### **2.3.5 Methods to study mental models**

The very nature of mental models has prevented researchers to illustrate them in a tangible fashion. The content and structures of mental models are thereby often inferred through mental models elicitation methods which use written/verbal interviews, think aloud protocols, drawings, concept mapping, naturalistic observation, repertory grid technique, concept listing and pair wise rating (Zhang, 2010).

The technique that has been implemented in our study is simple written interview where subjects had to externalize their mental models by answering yes/no to a set of questions. It comes under indirect probing strategy in interviews (Sasse, 1989; Bruce, 1999).

## **2.4 Summary**

This chapter relates to the literature review of automation and human factors research aiming to illustrate the underpinning attributes and the basis of the modern human-automation (systems) designs and development. The history and purpose of introduction of automation in human-machine systems has been gone through briefly, which is followed by the description of levels of automation. Models for types of automated functions of the systems and levels of automation continuum from the view point of different researchers have been elaborated concisely.

In human factors research review, the objectives and perspectives of this branch of science have been rundown quickly. The automation usability related issues that made the

failures of the socio-technical systems un-cope-able in the past and the research contributions which were then contrived and are still being carried out to overcome and deal with the stated problems have been overviewed.

The chapter also includes the constituents of human factors literature which have been utilized in the presented work in a little more detail. These are Rasmussen's model of human behavior, Situation Awareness (SA) and Mental models. The role and importance of each of these aspects of human factors in making the design of human-automation system even more effective and proficient have been conferred.

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## 3. Critical Review of ADAS

### 3.1 Introduction

Heaved by human necessities and demands and empowered by scientific, technological and societal progress, more and more aspects of our life are being technically assisted or automated. Among a number of examples is a transportation domain, where in the sky commercial aircraft are being highly automated, and on the roads a steady revolution has been taking place towards assisted, highly automated or fully automated cars and trucks for the last two or so decades (Flemisch et al., 2008).

Road accidents and vehicle collisions hold a major share in the causes of injuries leading to death and disability, and a foremost apprehension for trauma medicine, public health and traffic safety, around the globe. Based on literature survey, almost 90% of all traffic accidents can be attributed to driver impairment or error, for instance, due to fatigue, inattention or drowsiness at the wheel (Brookhuis et al., 2001). Safety and the awareness of the surrounding environment have been proved to be the initial push for the introduction of automation in the automobiles and they are still playing a key role. Other factors like driver's work load, comfort, transport infrastructure, traffic efficiency, etc. which had also been found to have direct/indirect influence on situation awareness and safety, started gaining attention along with and became the reasons to set up automatic systems and control systems within the vehicles. Since then quite a good number of advanced driver assistance systems are being introduced in the automobiles to balance or mitigate human performance variation impact and achieve situation awareness, greater control and safety.

Advanced driver assistance systems (ADAS) have been one of the most dynamic research areas of Intelligent Transport Systems (ITS) recently. ITSs aim to realize enriched

safety, comfort, traffic efficiency and environment protection, energy benefits and to lower economic cost due to accidents. It integrates three fundamental components of people, roads and vehicles by means of state-of-the-art electronic technologies.

### 3.2 Advanced Driver Assistance Systems (ADAS)

The needs of users, in a general sense, in road transport stalks from unsatisfactory conditions which could either be driver induced or traffic induced. Solving the need for support to mitigate the risk of such vulnerable factors/conditions was thought to be realized through ADAS (Carsten and Nilsson, 2001). Governments in North America, several European countries, Australia and in Asian Pacific countries set challenging targets for the improved road traffic safety by the year 2010 and most of them have been achieved to a great extent. The most recent project that has been completed in EU was Highly Automated Vehicle for intelligent transport HAVEit and in Japan its Advanced Safety Vehicles ASV.

#### 3.2.1 Categories of ADAS

Through ADAS the driver facilitation in performing driving operations to attain more regulated and smooth vehicle control with increased capacity, associated energy and environmental benefits by providing real time advice, instructions or warnings has been intended (Piao and McDonald, 2008). More or less five functions have been defined for the advanced assistance systems, which are as follows (ASV Phase 2 Consortium document 2000):

- **Enhancement of driver perception:** These systems help the driver to perceive the environment around the vehicle easily, e.g., smart headlights, Around View Monitor (AVM), etc.
- **Information presentation:** The function of the systems that fall under this category is to provide objective information to the driver. Typical examples are navigation systems and systems providing information on traffic and road conditions. This function also aims to encourage the driver to pay attention to the potential risk around the vehicle, e.g., night time pedestrian/obstacle monitoring system.
- **Warning presentation:** The system predicts the potential risk using detector information and encourages the driver to make appropriate actions and vehicle control,

e.g., Lane Departure Warning (LDW) system, Blind Spot Warning (BSW) system etc.

- **Accident avoidance control:** The systems under this class are activated when the driver is not found to perform any corrective action against the hazardous situation or adequate action to avoid accident, although the other assistant systems have warned the driver. Warning systems should be working in advance before the "accident avoidance control" system will be activated. Examples of such type of systems are Forward Collision Avoidance (FCA) system, Lane keeping assistance system, Curve overshooting prevention system, etc.
- **Driver load reduction control:** These systems tend to reduce the driver fatigue by alleviating the control workload. The driver will be able to pay more attention to the traffic environment of the vehicle, e.g., Full speed range Adaptive Cruise Control (ACC) system with Brake control.

In HAVEit (Consortium public document, 2008), the levels of assistance through ADAS have been described as the following four; manual driving; assisted driving which includes manual driving with automation support; semi-automated driving; and highly automated driving with driver support, as shown in Fig. 3.1.

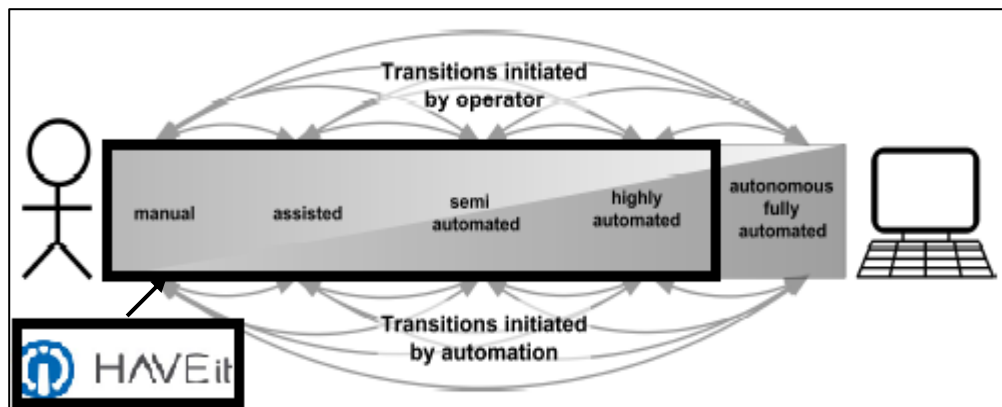


Figure 3.1: Automation spectrum, automation regions and transitions (from Flemisch et al., 2008)

In HAVEit, *highly automated driving* has been focused on and there is no *fully automated driving* where the human is only a passenger. In highly automated driving, the high percentage of the driving can be performed by an automation called the co-system, but the human driver would still be in control of the highly automated vehicle. The distribution of the driving task between driver and automation is not static, but a dynamic repartition, where driver and co-system can find an optimum balance depending on the situation. Both the driver and the co-system can influence the task performance.

- the driver can influence the performance e.g. by switching to a higher or lower level of automation
- the co-system can have impact on task performance e.g. by recommending or, by escalating towards a transition to another automation level in urgent situations or in occasions of work overload/ under load.

This task repartition has been accomplished with a set of interaction schemes, as illustrated in Fig. 3.2, and with a concrete design of interaction between driver and co-system via a primary driving interface as well as switching and display devices. The test of these interaction schemes and the human machine interfacing had been the special focus of this project (HAVEit Consortium public document, 2008).

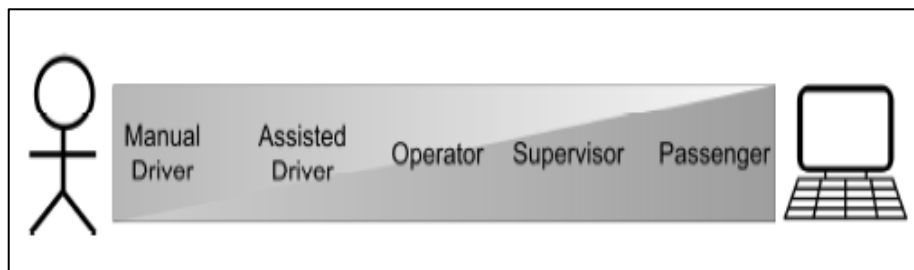


Figure 3.2: Potential role spectrum in vehicle assistance and automation (from Flemisch et al., 2008)

### 3.2.2 Expected benefits of ADAS

As a combination of vehicle and information technology, the implementation of ADAS holds potentials for;

- More convenient and safe driving
- Better overview and proper actions in complex driving situation
- Robustness against temporary driver inattentiveness
- Improved traffic flow and less disturbance due to inadequate maneuvers
- Less accidents
- Improved fuel consumption and reduced economical cost and pollution.

### 3.3 Human Factors in driving automation

There is no doubt that the dominant model for advanced intelligent vehicle design or advanced driver assistance systems design comes from the aviation industry. Benefits of

automation in aviation have served as the basis to explore and establish contexts where automation of drivers' tasks is likely to yield advantages. Similarly, the evaluation of human interaction with automated systems in aviation, nuclear power plants, marine units, advanced manufacturing plants etc., and the conclusions drawn heavily on this experience have also been used as a means to gauge where problems with automobile automation are likely to arise (Stanton and Marsden, 1996). It is a matter of fact that automation changes the task and advanced driver assistance systems can fundamentally change the driving task and the role of the driver in this interplay. The most influencing factors that have been identified to be associated with the introduction of automation in automobile domain are as follows:

- **Mental workload fluctuation:** It has always remained a central concern for automation introduction. Automation can decrease driver mental workload by reducing the amount of attentional resources required for a task, but if it is reduced to an unreasonable level then it becomes a threat to situation awareness and adequate response time. The evidence suggests that a psycho-physiological consequence of less activity is abridged vigilance. Automation can increase workload and attentional demands if system behavior is too complex to understand or if the system fails, which leads to more attentional resources focused on the operation of the system than task of controlling the vehicle. Both mental overload or underload could be detrimental to driving task performance (Young and Stanton, 1997).
- **Trust in automation:** Trust, generally, appears to be regulated by the driver's perception and expectations of the capableness of the system and evolves over time. If the driver perceives the system to be more capable of performing a task then it will be trusted and relied on, and *vice versa*. Too much reliance can lead to complacency, and too little reliance may result in technology being ignored and negating the social benefits associated with the system (Stanton et al., 2007). For appropriate trust and reliance, the proper information on the capacities of the automated or assisting system should be conveyed to the driver.
- **Behavioral adaptation:** According to Organization for Economic Cooperation and Development (OECD) expert group (1990), behavioral adaptation is defined as "the behaviors which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change". Behavioral adaptation may appear in many different driving tasks: in change of speed, change of



following distance, way and frequency of lane changing, way and frequency of overtaking, reaction/response time, late braking, change of level of attention, etc., (Saad, 2006). Negative adaptations reduce safety; it should not be lost sight of.

- **Loss of skills:** Automation may lead to loss of skill. If people can perform a task relatively well but do not perform this task for a long time, they lose the skill to perform that task. It should be ensured that (minimum) requirement for a driver to manually operate the vehicle will be satisfied, so that drivers can cope with system failures (Toffetti et al., 2009).
- **Driver-in-the-loop:** The conception of *driver-in-the-loop* attributes to the active involvement of the driver in the driving task and the awareness of the vehicle status and road traffic situation. Being in-the-loop means that the driver is monitoring information, detecting emerging situations, making decisions and responding as needed. Driver is not a passive observer and is not losing his/her normal awareness of the surrounding environment. On the contrary, *out-of-loop* corresponds to the unawareness of the driver to immediate driving state or traffic situation. The state of being out-of-loop precedes the diminished ability to perceive system faults or failures and manually react to them (Endsley, 2012). Inadequate mental workload, reduced situation awareness, negative behavioral adaptations, system's poor design etc., indeed are the contributors to out-of-loop performance.

### 3.3.1 Design principles of ADAS

*Driver centric* and *context-sensitive* automation for enhanced safety and improved fuel efficiency have been, no doubt, the primitive design basis for ADAS. However, in the context of information presentation and interaction with displays and controls, the design principles of ADAS generally emphasize that (Thalen, 2006; ASV document, 2005; HAVEit consortium, 2009):

- Driver should always remain in the loop and in control of the system and vehicle.
- Driver should always be able to override system actions at any time under normal and safety critical driving situations.
- System intervenes to avoid collision or to try to regain stability and control only in case that driver is not responding or driver can't handle the situation.
- Driver should be explicitly informed of the conditions that result due to system

activation and deactivation. He/she should be able to easily determine the system state. There should be clear and adequate feedback about whether the system is working effectively.

- Driver should be informed of the conditions when system operation is limited or is not guaranteed.
- Driver should be informed of any transfer of control between the driver and vehicle; and between different levels of automation.
- If any information or action is not available due to a system failure, it should be informed.
- If symbols are used to notify the driver of any condition, then standard symbols should be utilized.
- Information which has the highest safety relevance should be given priority
- Visually displayed information should be designed such that the driver is able to assimilate the relevant information with a few glances which are brief enough not to adversely affect driving, etc.

In order to address human factors concerns and to achieve ADAS design goals exhaustive and rigorous research activities are being undertaken over the past decade or more. For example, in Europe led projects, like PREVENT for preventive and active safety applications for driving; SPARC: Secure Propulsion using Advanced Redundant Control for driver assistant systems for heavy good vehicles; HAVEit: Highly Automated VehicleEs for intelligent transport; and Japanese project ASV: Advanced Safety Vehicles: phase I; II and III, substantial work has been done to determine the proper layers of assistance and safe levels of automation for the purpose. Projects like Adaptive Integrated Driver-vehicle Interface (AIDE) have made extensive contributions for adequate interface designing taking into account a number of driver-system interaction aspects. Guidelines, checklists and assessing criteria have been suggested. To evaluate compliance with the design principles of ADAS, high-fidelity simulators have been utilized.

Apart from these projects, researchers from different institutions have also added to the ADAS research to furbish its investigations, e.g., (Stanton and Marsden, 1996; Carsten and Nilsson, 2001; Brookhuis et al., 2001; Amditis et al., 2010; Meng et al., 2004; Ravani et al., 2011; Wiese and Lee, 2007; Kodagoda et al., 2007; Vanderhaegen, 2012; Piao and Mcdonald, 2008; Marsden et al., 2001; Larsson, 2012; Thalen, 2006). For smart collaboration between human and driver; to develop adequate trust; to determine driver

response to alarm and support functions, to analyze mode confusions, etc., studies have also been carried out, for instance, (Inagaki, 2008; Itoh, 2001; Itoh, 2008; Itoh, 2012; Itoh, 2011; Inagaki et al., 2008; Abe and Itoh, 2008; Furukawa et al., 2003; Horiguchi et al., 2010).

For driver-centered ADAS design and to ensure high functional safety of the systems, the Research and Development (R&D) labs of automotive companies have made a huge share in these investigations. For example, (Boer et al., 1998; Boer and Hoedemaeker, 2000; Goodrich and Boer, 2000; Goodrich and Boer, 2003; Goodrich and Boer, 1998; Goodrich et al., 1998; Salvucci et al., 2001; Ohno, 2001) etc. HAVEit project in Europe (Consortium public document, 2009) and ASV project in Japan (Public document, 2005; 2010) encompasses all the major automotive companies.

### **3.4 Training of drivers on ADAS**

Unlike other safety critical domains, in driving automation a very little stress has been exerted on the notion of training of users/operators to help them develop functional mental models from the commencement. There does not seem to have considerable work on proper mental model building to address aforementioned usability problems before they start interaction with new technologies. The huge emphasis is being put on the optimization of the design of interfaces to deal with behavioral adaptation, out-of-loop performance or situation awareness concerns but the realizations of methodologies and learning tools that can make drivers overcome the discrepancies in their mental models towards assisting system from the very start have received little attention. In aviation, power plants, marine industry, etc., operators are being trained to have robust human-machine interaction along with optimized interface designs.

Even the empirical investigations carried out within HAVEit project utilizing high fidelity simulators showed that trained drivers on the systems did well than naïve users, as they had better performance in symbols, system status and system capacities recognition. There is no doubt that ADAS users have opportunities to learn during its use that how their mental models of the systems differ from actual system behavior, but their original mental models have the tendency to prolong this learning or even halt it. Thus, the presented work documents our attempt to explore that whether driver's preconceived prospects about the assisting systems can be reformed using different instructional techniques or the formal training procedures are the only solution.

### 3.5 Summary

The chapter has covered briefly but incisively the overview of Advanced Driver Assistance Systems (ADAS). It has been seen that what are those factors and elements that have provoked the installation of advanced technologies in the vehicles. How the influencing factors and needs have been tried to deal with utilizing ADAS, has been elaborated through discussion on categories of ADAS, and their expected benefits for road traffic environment and indeed road traffic safety.

The chapter also provides the synopsis of human factors associated with driving automation. Design principles of ADAS have been gone through to grasp the idea that how the potential problems associated with driving automation have been planned to address and mitigate. In the end, it has been tried to shed light on the concerns regarding the training of drivers on ADAS, which is also the focus and purpose of the current research work.

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## 4. Probing mental model development of naïve users of ADAS

### 4.1 Introduction

As it has been elaborated before that in joint systems, automation cannot be considered in isolation from the people who use it and adapt it. In order to achieve overall high performance and targets, automation and people have to coordinate as a single team. For the purpose, especially in safety critical domains the users/operators are trained to nurture functional mental models of the automated systems they are teaming and working with. A functional mental model refers to mental representation that user employs to use, control and supervise a system in a satisficing manner (Wieringa and Stassen, 1999; Norman, 2007; Carroll et al., 1987; Zhang, 2010; Heymann and Degani, 2002; Goodrich and Boer, 1998).

The reasons of training have also been mentioned earlier in discussion on mental models that people tend to speculate about the underlying mechanisms of a given system based on their expectations and understanding. They believe that their mental models are valid if the system behaves as expected or inoffensively. Mental models of users hold a share in establishing causal relationships based on co-occurrence of events. Whereas, the generated system behavior might be for reasons that differ from the ones the user accepts as true. To develop misconceptions about a system is thereby very common for users and it is also often hard for them to come out of fallacies on their own. The unpredictability of the time required by the user to improve mental models through learning from experience

puts interaction at constant risk. Thus operators get training to interact with automation and to understand the coordination requisites that are likely to be misperceived by them.

Driving with ADAS also requires the drivers to have functional mental models of the systems especially in the context of its assistance capableness and new coordination demands. It is because that the robust interaction between the driver and the artifact is essential to realize the objectives of the introduction of these advanced technologies in the vehicles. However, unlike personnel involved in aviation, marine, process industries, or power plants etc., the typical driver has almost no expertise on the systems. Drivers are not trained to construct and develop functional mental models of the technology from the very beginning. Detailed information about the working conditions of the systems is provided in vehicle's manual and the owners/drivers have to go through these manuals by themselves. Since the domain of automobile holds a tremendous variety of users, most drivers are unlikely to have read these or thoroughly. Accordingly, they can typically construct naïve/prejudiced mental models of the working of the technology, its assisting capacities and the subsequent demands of interaction.

Compared with the above mentioned safety critical areas, no doubt, the sophistication of automation in automobiles is far less, but the impacts of naivety or partiality of users' mental models about the system on the interaction could be equally unsafe. This notion motivated us to explore the development of mental models of naïve users of ADAS while driving, to apprehend the absence of vital instructional aids in automobile domain and the efficacy of users' experience based learning of ADAS. These points spurred us to ask the following questions:

- If a user's general mental model on an ADAS lacks essential aspects of the system's working scheme, can they nevertheless recognize, learn and correct errors in their model using only their driving experience without any kind of explicit feedback?
- The act of driving usually occurs together with other activities, so does the amount of cognitive resources a user spares for activities other than driving influence their ability to learn about the system?
- The important information about the systems should be confined to user manuals, and let the drivers learn on their own or do these smart technologies call for clear elaboration and training for attaining genuine safety?

Thus to assess the response of ingenuous users of ADAS under the influence of

their partial mental models about it and to find answers to the above stated questions an experimental study was conducted utilizing a driving simulator. A Lane Departure Warning (LDW) system with a hidden speed threshold, set to differentiate system behavior, was employed as a model assistance system to be learned by naïve users. We therefore investigated whether drivers with only minimal knowledge of LDW system could recognize the speed threshold of the system and update their mental models about this in a dynamic driving environment. An additional objective of this study was to elucidate the effects of technology use, with insufficient knowledge, on driver-system interaction, situation awareness and safety. Here, the meaning of ‘situation awareness’ is not confined to a driver’s awareness of the surrounding conditions, aided/unaided by the system, but extends to knowledge of the system’s state itself, i.e., *automation awareness*.

Our study involved two groups of participants, Group 1 and Group 2. The first group performed only the driving task, while the second group executed a secondary task in addition to the primary driving task. The purpose of imposing a secondary task was to introduce a multi-task setting, since activities such as operating navigation system, operating hardware switch controls, conversation, cognition, planning and so on are carried out commonly. Our aim was to examine the impact of multitasking on the development of mental models and assess how such activities alter a driver’s perception, compared with situations in which driving is the only task. These schemes enabled us to appraise that how *learning from experience* is affected when a driver’s cognitive, visual, auditory and physical resources are broadly distributed and preoccupied with tasks other than driving. The secondary task in our study demands drivers to share their cognitive, visual and physical resources; though sharing of auditory resources was not required.

It was assumed that a multitask setting would affirm that in dynamic driving environments, where drivers are not exclusively focused on driving, their ability to observe an assisting system’s state fluxes would impair, which negatively affects their awareness and hence delays mental model improvement process. Consequently, it was hypothesized that Group 1 participants would be better at recognizing the LDW system speed threshold and would more easily improve the mental model of its operation.

## 4.2 Drivers’ awareness with ADAS

In human-machine systems, humans are using, controlling and supervising technological artifacts employing their motor skills, sensory properties and cognitive capabilities



(Wieringa and Stassen, 1999). Machines are used with an expectation that they will extend human abilities to attain goals more proficiently and with less effort (Inagaki, 2008). ADAS have also been devised to reinforce driving operations, especially in the context of *situation awareness (SA) and safety*, as research and investigation has shown that *driver inattention* is a major contributor to inner city and highway crashes.

Situation awareness (SA) is a three-level construct, i.e., perception, comprehension and projection of elements in an environment within a volume of time and space, as described previously and demonstrated by Fig. 2.3 (Endsley, 1988). Hence, ADAS are intended to help drivers perceiving, comprehending and projecting the situation in a timely manner while a vehicle is being driven. The SA model in Dynamic Decision Making, illustrated in Fig. 2.4 in Chapter 2 (Endsley, 1995), and other studies (Heymann and Degani, 2002; Parasuraman et al., 2000; Stassen et al., 1990; Johannsen et al., 1994) show distinctly that these levels have direct/indirect affinity to the factors like *preconceptions (mental models and expectations), abilities, experience, and training*. When automation is introduced, these individual factors, among others, can contribute considerably to "*changes in vigilance and complacency with monitoring*" (Endsley and Kiris, 1995), in the users of the systems.

During the act of driving, the driver's basic situation awareness is what he/she experiences without the aid of any assisting system. This basic information acquisition and data integration scheme of the driver, which is based on conventional driving tactics and his/her own way of exploring the environment for clues, can be divided into subclasses upon insertion of smart assisting systems as shown in Fig. 4.1.

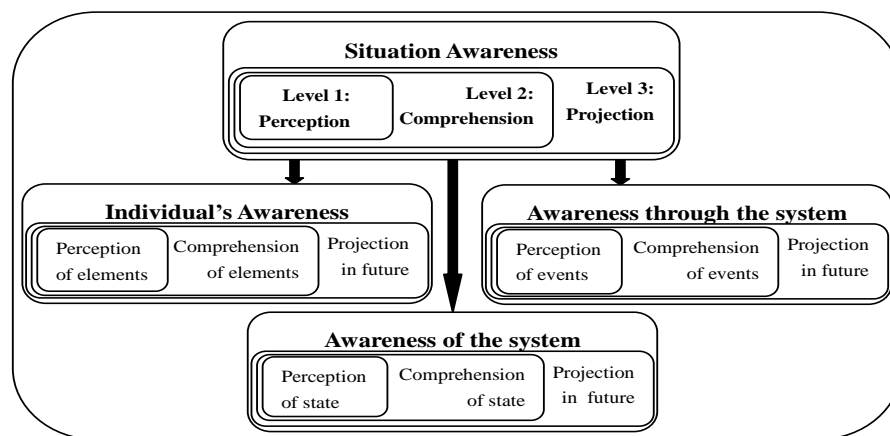


Figure 4.1: Classes of Situation Awareness (SA) with ADAS

If a driver starts using the system and his/her own mental interpretation of its operation

does not functionally match the target system's behavior, this will affect not only the individual classes of *awareness through the system* and *awareness of the system*, but can substantially deteriorate the *individual awareness*. It is because that the assistance which automated systems provides can and will lead to an attitude of reliance/over reliance on them (Wiener and Curry, 1980). This influence can further weaken the decision making as well as inhibit the execution of appropriate actions and ultimately reduce safety. The driving environment is usually not only less predictable, but also the margins of errors are very small. Thus, in a multi-task dynamic driving environment that even includes an ADAS, drivers' awareness and attentiveness to system's state remain doubtful. The time required for a driver to develop an understanding of ADAS functioning through experience, the succinctness and accuracy of this understanding, and the degree of safety enhancement that the use of the system might provide, are all unknown. However, the direct/indirect influence these general mental models can have on drivers' cognitive and physical behavior can be anticipated, which demands attention and is the focus of this chapter.

### 4.3 Lane Departure Warning (LDW) system

A Lane Departure Warning (LDW) system helps prevent lane departure due to driver inattention or erroneous estimation of lane markings/boundaries. Vehicle's position and direction in a lane are analyzed after the detection of lane markings on the road, using a camera as a sensor, and the possibility of lane departure is calculated. Warnings are issued using sound and visual displays, and in some cases also haptically.

The LDW system requires certain conditions in order to operate. In most vehicles marketed by different companies, the LDW system remains in standby mode until a speed of 50 or 60 km/hr is reached. Conditions of rain or snow, fog, dusty wind and sudden changes in brightness (due to sun, headlights, etc.) may prevent appropriate system operation, and operations are also problematic on roads with sharp curves, roads with multiple or dim markings, and roads with lanes that are unusually narrow or wide. The system stops working when the vehicle is travelling close to a vehicle in front that obstructs the camera's detection range. When the LDW system cannot function normally, its operation is automatically cancelled. When the system is in operation, it is required that excessive or sudden steering maneuvers should be avoided. The conditions for operations are more or less the same regardless of the manufacturers (Owner's manual 2010; 2011;

2012).

## 4.4 Experiments

### 4.4.1 Apparatus

To provide a highly realistic driving environment, PreScan® software version 6.1.0, was used for ADAS simulation in this research. The driving simulation environment was rendered from a first-person perspective and displayed on three 30-inch monitors located in front of participants, to replicate an immersive driving experience. Figure 4.2 presents the setup of the driving simulation. The simulated vehicle was equipped with a LDW system and controlled with a Logitech MOMO Racing Force Feedback wheel, brake and accelerator pedal, with automatic gearshift. The steering wheel could provide haptic feedback.

It is a matter of fact that the validity of the simulated environment is always restricted and debatable, but we find it necessary to inform that the PreScan® software has been specifically designed for ADAS simulation. Its use by different research labs across the globe, and its recommendation by the automotive company employee not only made us to select it for our study purpose but to be unambiguous for the obtained results as well.

Laptop computer running PsychoPy2 (Psychology software written in Python) was utilized to provide subjects with a secondary task when they were driving a simulated vehicle.

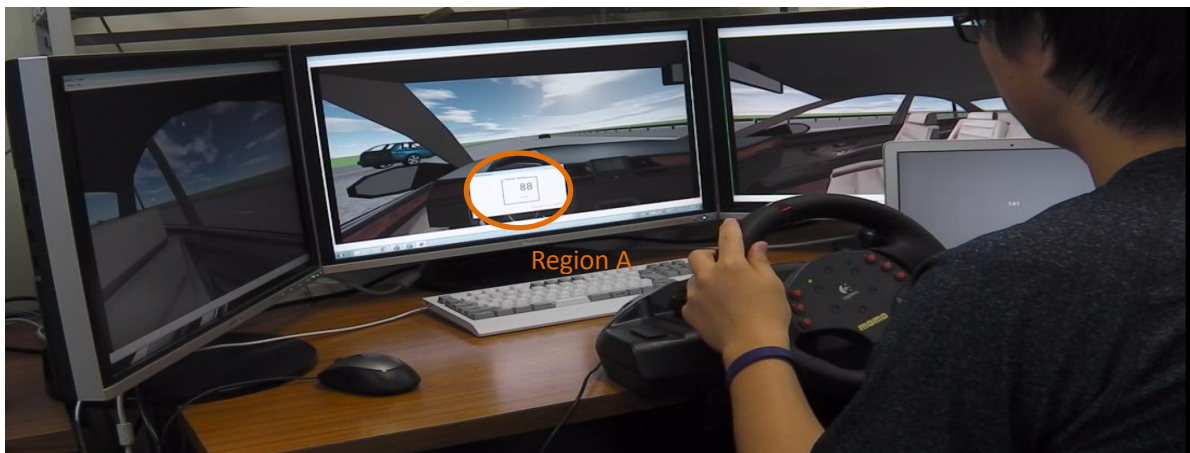


Figure 4.2: Experimental setup

### 4.4.2 Participants

Twenty-four participants (including 3 female), aged between 21 and 40 years, took part in the study. All participants had a valid driver's license and at least one year of driving

experience, but none of the participants had an experience of driving a vehicle equipped with the LDW system. More than half of the participants had heard about this system and the rest were given commonly available information about it. No detailed written or verbal material about the operation of the system was provided to the participants. This was done to replicate a situation where a driver starts interacting with a new on-board technology while lacking sufficient knowledge about it.

#### 4.4.3 Design and procedure

A simulated two-lane freeway, the starting point of the experimental driving setting, was created which merged into a three-lane highway environment. Figure 4.3 presents the driver view and the top view of the driving simulator test track. Figure 4.4 depicts the driving scenarios including the curved road segment entering highway and car following on highway. Road signs were used to alert drivers to speed limits and for demarcation of road segments. The initial two-lane road had speed limit of 40km/hr, the curved road section used to enter the highway had 30km/hr speed limit, while the highway speed limit was 100 km/hr.

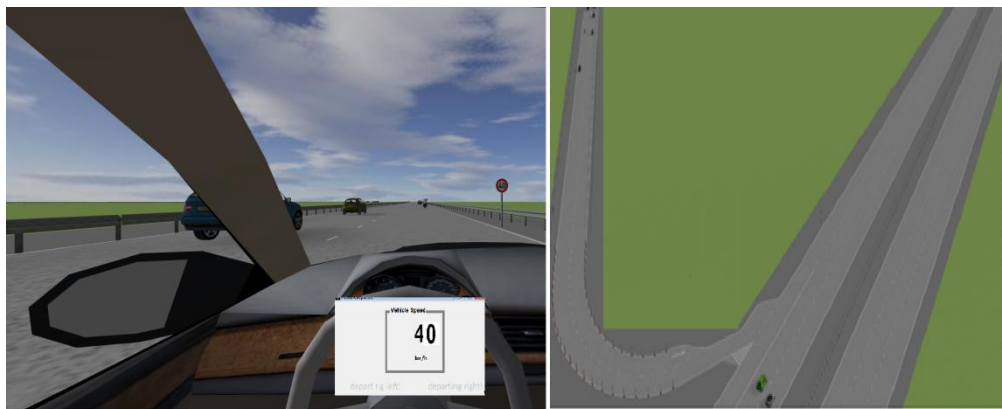


Figure 4.3: Screenshot of first person view and driving simulator test track



Figure 4.4: Screenshot of driving scenarios

In our experimental setup, the Lane Departure Warning system starts operating at a speed of 50 km/hr (Matlab files have been provided in Appendix III). A small graphic area located in lower portion of the central monitor screen was used to display speed and present warning text, i.e., “departing left” or “departing right”, indicated as Region A in Fig. 4.2. Figure 4.5 shows an enlarged view of this area. When warnings were issued, the warning text blinked in red. Warning was also simultaneously issued haptically through the steering wheel using rapid vibration.

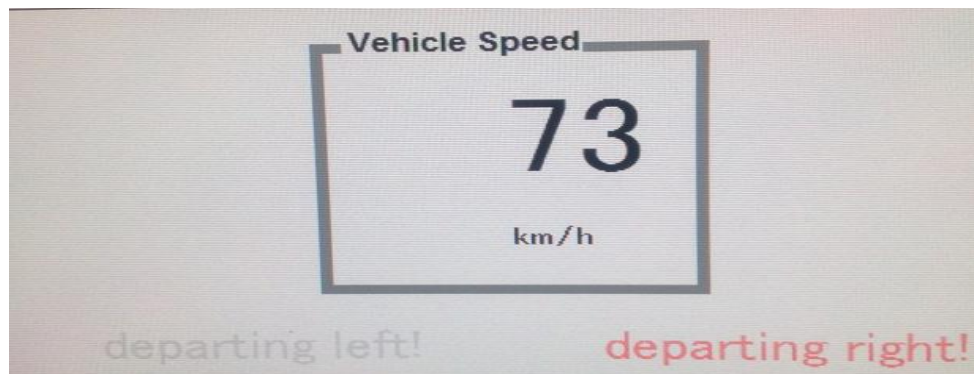


Figure 4.5: Enlarged view of Region A in Fig. 4.2

Also present in the simulation were a number of other automated cars, moving at set trajectories to imitate a dynamic traffic situation. The automated cars could change speeds and lanes, so drivers were asked to remain vigilant and avoid accidents. All participants received an explanation of the general setup and gave informed consent. Once the participants were familiar with the equipment, they completed a practice session during which the LDW system was switched off.

The participants were informed that the actual experiment would consist of five separate trials and that they would be given a questionnaire (Appendix I) in three parts: first at the beginning of the experimental session; second at the end of each trial; and third at the end of the completed session. They were told that there was no time restriction for completing a trial; however speed limits should not be ignored. The participants were randomly divided and assigned to two 12-person groups. The participants in Group 1 performed only driving task while those in Group 2 performed a secondary task along with the primary driving task.

In the secondary task, several three-digit numbers were displayed on the laptop screen positioned beside the large monitors. Participants were asked to respond to a

number if it was 130 or less, or 170 or more, by pressing the laptop's space bar. During each trial for Group 2 participants, the secondary task was presented for 48 seconds. The starting time of the secondary task interval was different for each trial, however the timings were standardized among the trials and subjects. The motivation for having this particular setting for the secondary task was to compel subjects to share and distribute their cognitive, visual, spatial and physical resources, and to have dynamic time-sharing performance. We wanted to determine if the time sharing characteristics of two tasks scenario and driver's preoccupied resources influence a driver's ability to learn from experience, i.e., develop a functional mental model of the LDW system.

## 4.5 Results and discussion

### 4.5.1 Participants' original mental models

The questionnaire given to the participants at the beginning of the experimental session asked them; *if they know what the Lane Departure Warning System is, then state its function*. The motive for asking this question was to ensure that subjects had some internal representation of the system's working at that stage. Their statements helped us to infer their mental models and then to categorize them. Thus, on the basis of the participants' understanding of the events that trigger the LDW system operation in a vehicle, the mental models were sorted into three classes A, B and C, and presented as state transition diagrams in Fig. 4.6.

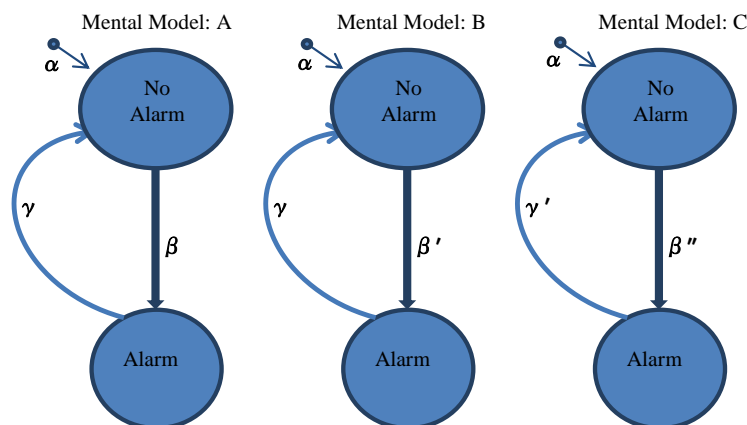


Figure 4.6: Participants' mental model classes for the LDW system state transitions

According to all the participants, no matter which mental model class they belonged to, when the LDW system is engaged it becomes active for full speed range.

State ' $\alpha$ ' in Fig. 4.6 represents it. However, participants had different opinions for the events which trigger the operation of the LDW system. When the vehicle touches the lane boundary, it triggers warning from the system, i.e.,  $\beta$  was the transitional factor in the states of the LDW system according to the participants in mental model class A. For participants in mental model class B, it was  $\beta'$ , i.e., when the vehicle crosses the lane boundary. When the vehicle gets inside the lane markings shown by the transition ' $\gamma$ ' in Fig. 4.6, then there is no more warning by the system and it acquires state ' $\alpha$ '. Mental model class C subjects were thinking that the transitional event for the LDW system state is the deviation of the vehicle from the center of the lane, i.e.,  $\beta''$ . When the vehicle returns to the center of the lane, depicted by  $\gamma'$  in Fig.4.6, the system stops giving alarm.

It is evident from Fig.4.6 that users' basic mental models about the operational speed of the system were lacking any boundaries that can restrict the system's operability. Once the LDW system was engaged, it was assumed that it is active for full speed range and there would always be warning by it when the conditions, they thought, were satisfied. The total number of participants in each class, and the number of subjects in these classes with respect to the task performance are shown in Table 4.1.

Mental Model Classes	No. of Subjects	
	Group 1 (Single tasking)	Group 2 (Dual tasking)
A	6	5
B	2	5
C	4	2

Table 4.1: No. of subjects in each class with respect to task performance

#### 4.5.2 Mental model improvement through LDW system experience

All the participants took approximately 300 seconds to complete a trial run. The results obtained through the experimental trials were as follows:

*Group 1:* Only 2 out of 12 participants became able to correctly recognize the speed threshold of the LDW system and update themselves. None of the other participants who performed the single driving task could detect the system boundary.

*Group 2:* In the second group, again, only 2 participants could discriminate that the

system became active only after reaching a certain speed but according to them that threshold speed was 40km/hr and 60km/hr respectively.

The mental models the successful 4 drivers were having originally have been presented in Table 4.2, and Fig. 4.7 shows the model of the LDW system operation which successful participants (almost) acquired through their observation of the system while driving. The other 20 drivers remained stick to their initial mental models.

Mental Model Class	Group 1 (Single Tasking)	Group 2 (Dual Tasking)
A	1	1
B	0	1
C	1	0

Table 4.2: Successful participants' primary mental models

The symbols in Fig.4.7 refer to:

$\alpha'$  = System is engaged

$s$  = Speed is 50km/hr or less

$s'$  = Speed is greater than 50km/hr

$\sigma$  = The vehicle is near or touching a lane boundary

$\gamma$  = The vehicle gets inside the lane boundaries

$\gamma''$  = Speed has become 50km/hr or less

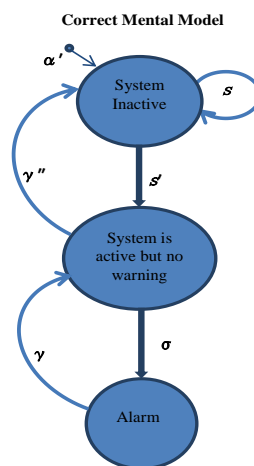


Figure 4.7: Model of the LDW system operation

Thus a total of 4 drivers out of 24 made it out. The high proportion of the unsuccessful subjects confirmed that the influence of the partial mental models is often so



compelling, that it becomes hard for the user to jump out of fallacies. Users experience the phenomena, but they might not be able to learn from it because their impaired mental model does not help them observe it. During the experiment, the participants' awareness level was tracked by asking them repetitively after every trial *if, at any time during the trial, they doubted the working of the warning system*. The unsuccessful subjects kept on saying 'No'. Under the governing influence of their mental model that the system was capable of working at full speed range, they did not monitor it. When they did not pay any attention to the system behavior and remained passive observer, they did not recognize the discrepancies in their mental model and did not make improvements. The finding also answers the first research question that if an ADAS user possesses a minimal mental model of the working capacities of the system, then there exist considerable chances that it affects their situation awareness (SA), i.e., awareness on both environment and automation and detains their learning from experience.

### 4.5.3 LDW system behavior recognition opportunities

The logged data reveal that the 20 drivers who were unable to recognize the LDW system's speed threshold nevertheless had reasonable opportunities to notice the behavior of the system. They did touch/cross the lane markings at the speed below 50km/hr during their trials, but they did not notice the absence of the LDW alarm when doing so. Figure 4.8 presents the frequency of the left boundary/right boundary lane departures under 50km/hr speed for both successful and unsuccessful participants in the two groups in five trials.

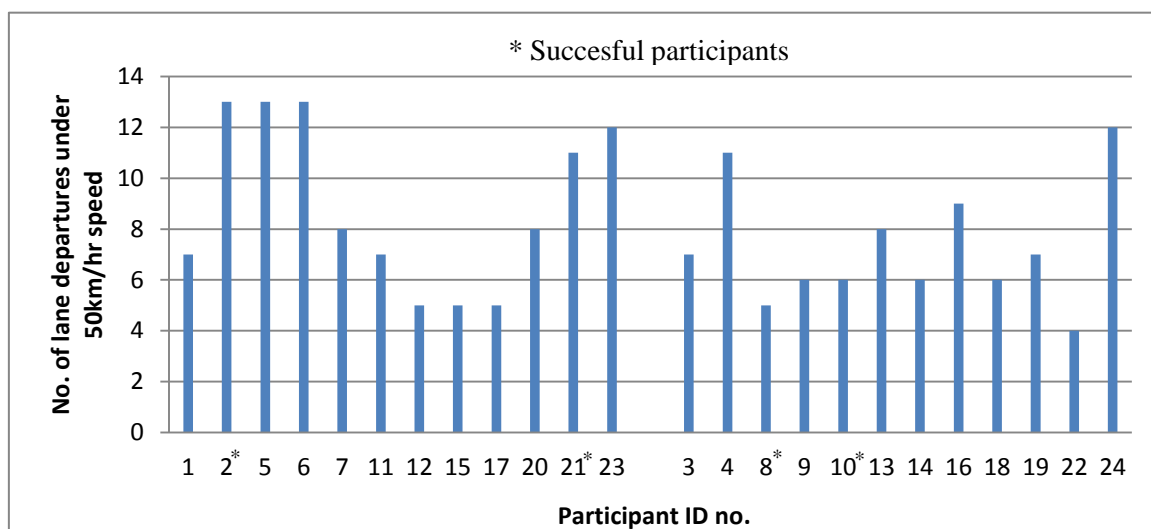


Figure 4.8: Frequency of Lane departures under 50km/hr across participants

Participant no. 2 and 21 from Group 1; participant no. 8 and 10 from Group 2 were those who recognized the speed threshold. It can be seen that all the participants had opportunities to learn system behavior irrespective of their driving styles and number of tasks being performed. It can also be perceived clearly that the 4 successful participants did not have ample lane departures to have more provocative exposure of the speed threshold to be proficient than other 20 subjects. In consequence, the reason the unsuccessful drivers could not notice the speed threshold of the LDW system was the prevailing mental interpretation they were having about its working. The mental image did not enable them to spare their resources for observing the system behavior. The factor unintentionally caused drivers to rely on the system to alert them of any unintended lane deviation. They could not keep themselves aware of the happenings at the speeds below 50km/hr and ultimately could not update their mental models.

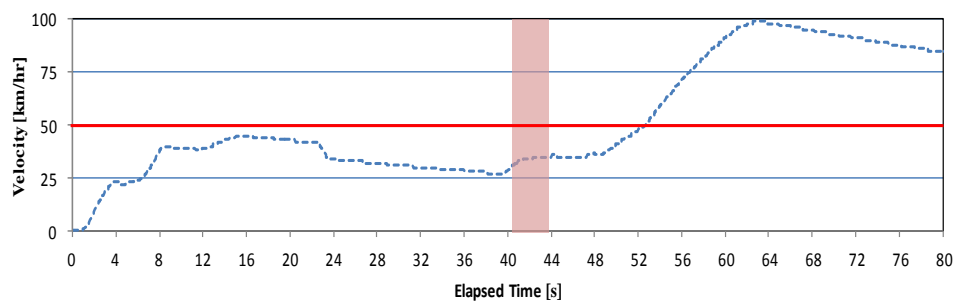


Figure 4.9: Velocity profile

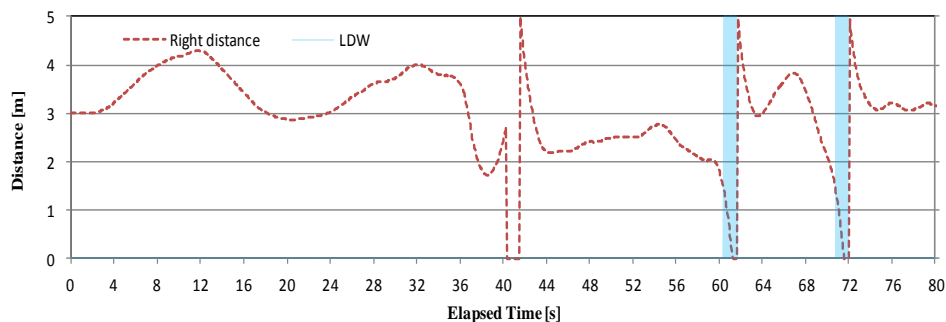


Figure 4.10: Distance to right boundary and LDW graph to time

Figures 4.9 and 4.10 show the driving pattern of one of the participants in a trial, chosen from among the 20 unsuccessful subjects. In Fig. 4.9, the  $x$ -axis represents the elapsed time in seconds and the  $y$ -axis is the vehicle velocity in km/hr. Red line represents the threshold speed, i.e., 50km/hr. Figure 4.10 shows distance to the right boundary and

lane departure warning to elapsed time. The vertical blue bars represent the LDW system warning events at speed above 50km/hr. The test track was 6m wide, with the center at 3m, also representing the centered position of the host car. The road had a 0.5m zone at the left and right sides, the threshold distance, which is why the distance graph does not extend beyond 5m. When the distance chart drops to zero, this indicates that the threshold distance was touched or crossed.

Figure 4.10 shows that the driver was touching the lane boundary during the time interval of 40-44 seconds and there is no warning indication. The speed during this time period is less than 50km/hr, depicted by a rectangular colored region in Fig. 4.9.

#### 4.5.4 Secondary task setting implications

The results were quite unexpected in the context of mental model improvement of the two groups of participants, corresponding to single task and multi-task scenarios. It was assumed that the number of the participants, who were performing the driving task only, would be greater at recognizing the LDW system's speed threshold. The multi-task setting would delay the mental model improvement process in Group 2. But the numbers of successful and unsuccessful participants obtained were the same for both groups. The finding led us to affirm that if there is an inadequate mental model of the capableness of the system, then its influence on the driver's observation and learning ability could be irrespective of the number of tasks being performed, and answered the second research question. However, in the event of improvement of mental model the accuracy of the recognition may be affected due to multitasking. As shown by results that the Group 1 successful participants did recognize the speed threshold more accurately than Group 2 drivers. Qualitatively speaking, the Group 2 successful participants' mental model of the working of the system was developed, but strictly speaking, *their models lacked precision in terms of the speed threshold value*. Thus, in this context, our hypothesis was correct, namely that the ability of drivers to observe the system's working margins when performing more than one task would be weaker compared to that of participants performing only the driving task.

Among Group 2 participants, again no big disparity was seen in the secondary task performance, as shown in Fig. 4.11. Participant no. 8 and 10 were the ones who recognized the LDW system speed threshold. The result demonstrates that the subjects who could not

recognize the system's speed threshold were not distinctly better in executing the secondary task in contrast to the participants who recognized. The unsuccessful participants were not seemed to be concentrating more on the secondary task accomplishment. The number of right answers was high and more or less stable between all of them.

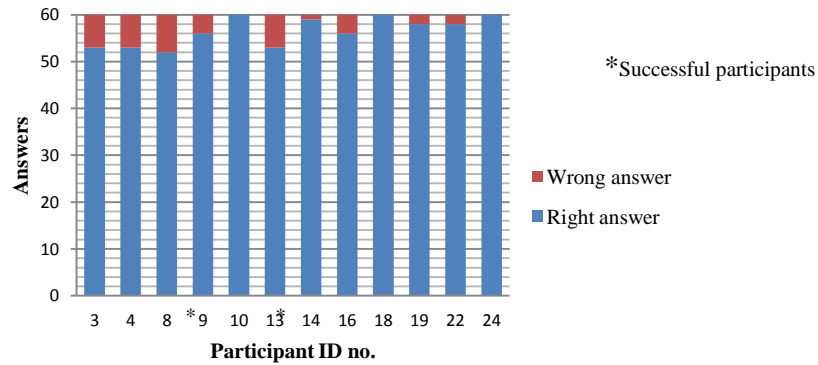


Figure 4.11: Secondary task performance

Hence, the outcomes allowed us to appraise that the existence of the secondary tasks could not be the merely basis of impairing drivers' observability, but their partial mental interpretations were among the reasons to undermine their perception and halt any development. These implications of users' mental models cannot be ignored in ADAS implementation.

Overall the subjects rated the system, when it is active, as an effective tool to maintain safe lane position.

## 4.6 Summary

This chapter narrates an empirical investigation aiming to explore that why in automobile domain, unlike other safety critical tasks; the introduction of automation does not accompany training and education of users/operators to cultivate functional mental models about it. It has been tried to find out that could the construction and development of functional mental models of drivers about ADAS be relaxed? Are the impacts of partiality of users' mental models in this domain so trifling, that their experienced based learning could address it and yet keep the overall interaction safe.

In the experimental study, one of the design boundaries of the LDW system,

namely the speed threshold for on/off operation has been considered. It has been analyzed that whether drivers with minimal knowledge and incomplete mental model of LDW system could recognize the speed threshold of the system and update themselves about this in a dynamic driving environment. The content of drivers' mental models was measured through written questionnaire. From a technical and design point of view, this working condition can be anticipated as a very *simple and easy to recognize* system feature. But the findings of the study affirmed that the users' with partial mental models of the LDW system could not identify this. Recognition of the system boundary by only 4 drivers out of 24 was a quite clear indicative. Drivers remained stick to their own mental interpretation of the working of the system, even though they intermittently experienced the situations wherein they touched/crossed the lane boundary below the system speed threshold. Thus, the use of advanced systems in cars by drivers who lack necessary knowledge of the systems' capacities threatens both situation awareness and safety.

The results of the experiments also reveal that the naivety and partiality of drivers' mental models could be powerful enough to impede the development of their mental interpretations of the technology. It can be seen that the number of the drivers who did not become aware of the LDW system's operating condition for both groups was regardless the nature of their tasks. We observed that the users' preconceptions and expectations, as well as the driving environment, could make them rely on the system to alert them of any unexpected situation even when the system was not operating. Due to prejudiced mental models, drivers' observability and judgment can get impaired and they could not keep themselves conscious of the on-going events. These factors can not only adversely affect the social benefits associated with ADAS, but in a broad perspective, *acceptance* of these systems too.

Hence, ADAS also entails its conceptual illustration and timely education of drivers about it.

## 5. On-board guidance: a potential tool to train drivers on ADAS

### 5.1 Introduction

People are apt to build mental models, which are both a knowledge structure and a dynamic tool which enables them to direct their interaction with external world and technological artifacts (Carroll et al., 1987). Mental models, no doubt, evolve as individual accumulates experience, but the cruciality to develop succinct and functional mental models may vary drastically from one sphere to another. In human-machine systems where safety is critical, *experience based learning* to foster mental models is not waited and counted on.

This postulation and the empirical study described in the previous chapter encouraged us to consider more in depth the working phenomena of driver's prejudiced mental models and how do the partiality of the models impact their learning from experience and behavior generation. On these grounds, conceptual models have been proposed to make the study of the influence of the partial mental models of an ADAS on driver's cognitive activity and resulting actions better apprehensible and to reflect it more logically.

It has been mentioned earlier as well that actual driving environments are not only less predictable but also incorporate really small error margins. The implications of drivers' biased mental models upon their situation awareness, i.e., awareness on both surrounding

environment (aided/unaided by the system) and automation from the former experimental study, also affirmed that in order to attain real safety with ADAS it is required to devise methods and means to support drivers in functional mental model building of the systems and their capacities from the beginning.

For this end the former study was extended to within-subjects experimental design, employing the same assistance system, i.e., Lane Departure Warning (LDW) System, having more operational boundaries in a driving simulator. To more rigorously approach the content of drivers' mental models about the new technology multiple methods; general questionnaire for concept elicitation and Situation Awareness Global Assessment Technique (SAGAT) to track participants' awareness level of automation and surrounding environment, were implemented. The study allowed us to more effectively estimate the impact of drivers' naïve mental models on their situation awareness and their capability of learning from experience. The results again confirmed that the drivers' biased mental models are truly a menace to the benefits associated with ADAS. The real road safety with these smart technologies calls for education of drivers about them.

Thus, this chapter also documents our attempt to explore that whether driver's preconceived prospects about the capableness of systems can be reformed using different instructional techniques or the formal training procedures are the only solution. It is agreed that the provision of specific information or conceptually-based instruction about the system functioning can support user's direct inferences about the system behavior and their role respectively (Kieras and Bovair, 1984; Norman, 1986). Hence, an *on-board quick guidance* on operational limitations of the LDW system through *visual display* as a candidate learning tool was employed and evaluated.

## **5.2 Influence of a biased mental model of an ADAS on driver's cognitive activity**

Mental models provide a context, according to which a user/operator perceptually delineates the operational domain, interprets sensory information and generates behavior. According to Goodrich and Boer (2003), mental models are "internal representations employed to encode, predict, evaluate, and communicate the consequences of perceived and intended changes to the operator's current state within the dynamic environment".

Based on Rasmussen's knowledge-based (KB), rule-based (RB), and skill-based (SB) behaviors; Fig. 2.2.(Rasmussen, 1983), they have described driver's sensory perception and behavior generation using a three level multi-resolutional society of interacting mental models. Figure 5.1 depicts the layout of their concept.

The roles and working of KB, RB and SB mental models while driving have been discussed comprehensively in their work (Goodrich and Boer, 2003; Goodrich and Boer, 2000; Goodrich and Boer, 1998; Boer et al., 1998; Boer and Hoedemaeker, 2000; Goodrich et al., 1998; Salvucci et al., 2001). They have deduced that when these models are enabled, they actively influence driver's behavior generation and when disabled they do not have direct impacts. When mental models are engaged, they hold attention whereby surrounding information is actively perceived and interpreted and when disengaged attention is released and no such active perception takes place (Goodrich and Boer, 2003). The mental models at the KB, RB and SB levels not only govern the perception and behavior actuation at their individual level but also influence the associated ones.

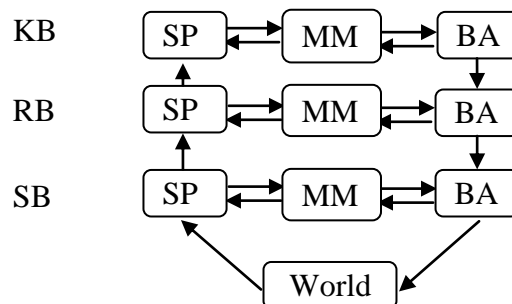


Figure 5.1: Communication and Control within a society of mental model agents. SP= sensor perception; MM= mental model; BA= behavior actuation (Goodrich and Boer, 1998).

This notion led us to infer that if a driver possesses the partial/biased KB mental models about the automation, i.e., advanced assisting systems, and starts interaction based on it, then it would for sure impact the awareness and generation of behavior at the RB and SB levels; which a driver used to have without automation and would have with automation. As long as the KB mental models about the assistance capableness of the system and its coordination demands remains partial, they keep on getting engaged or enabled inadequately; which furthermore might detain the driver's learning from experience. It has been elaborated more in detail in the following sub-sections.



### 5.2.1 Agent model of a driver's typical cognition cycle

Figure 5.2, which is modified from (Tamaki; and Sugikawa, 2011) and which is inspired by the theoretical framework proposed by Ballet et al., (2009), for studying and modeling drivers' mental representation; demonstrates the cognition cycle that takes place in driver's cognition covering from perception to action selection during manual driving. Mental interpretation of how to accomplish a driving operation in an acceptable manner holds a significant share in carrying out this cycle. The driver constructs the mental interpretation of the event schemes and basic procedures for different driving tasks at the time of learning driving and then improves it through practice in daily life. This primitive knowledge helps him acknowledge/build rules as requisites of driving operation for different situations, which keep on getting stored as "familiar states" or routine states in the core, i.e., working memory, as shown by  $S(T)$  in Fig. 5.2. Accordingly skills are developed.

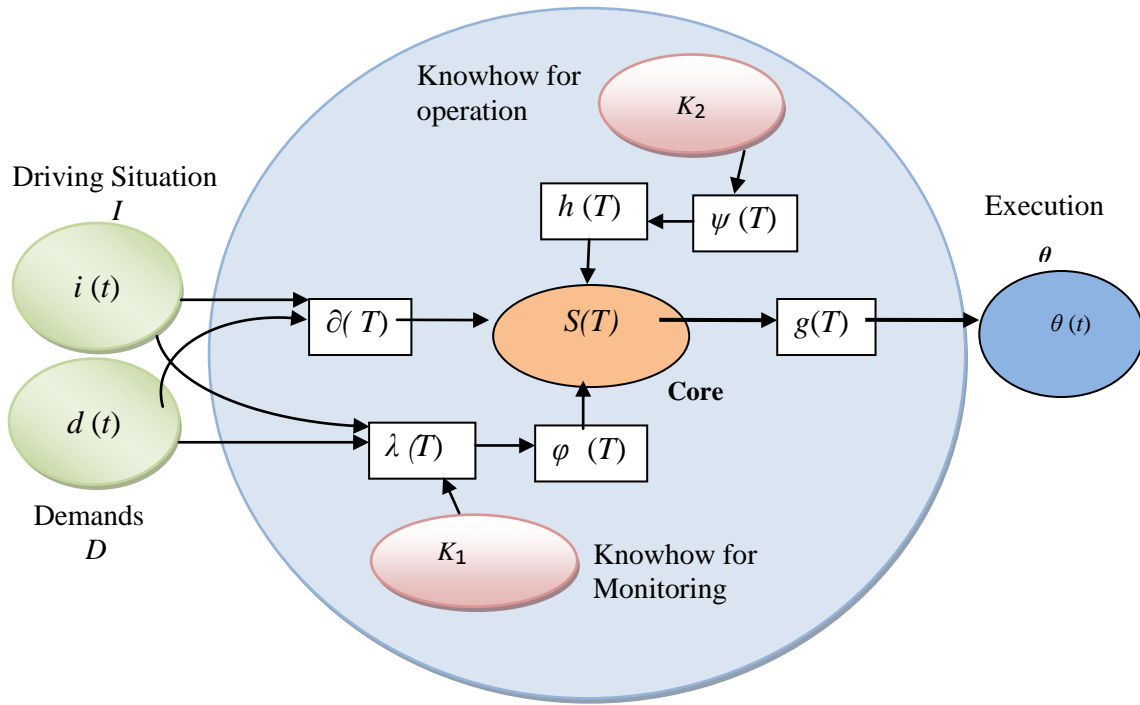


Figure 5.2: Agent model of a driver's typical cognitive activity while driving

In the followings, it is to be noted that " $t$ " is the time scale which represents an ongoing event, whereas " $T$ " is the time taken by the individual to process these conditions, give them some meaning, update them and act accordingly in that particular event context. Based on this, in a driving situation  $i(t)$  and under the demands  $d(t)$ , whether traffic or personal, the driver engages the RB or SB mental models and scans the environmental

information. If the information is identified  $\partial(T)$  as a familiar state  $S(T)$ , the driver then enables the SB or RB mental models; and the decisions  $g(T)$  and the actions  $\theta(t)$  are undertaken quite straightaway from the established collections in the working memory. Whereas if the situation and demands are new or unusual/ less familiar to the driver, the higher level cognition, i.e., KB mental models, are activated to accomplish a driving operation. Utilizing available knowledge (from long-term memory) on monitoring of the environment or vehicle, the KB mental models are engaged and the collected information is interpreted  $\lambda(T)$  and recommendations  $\varphi(T)$  are made. In core, in case the recommendation  $\varphi(T)$  corresponds to any familiar state, then the routine RB or SB action can be implemented, otherwise the KB mental models are enabled. The matching  $\psi(T)$  of the cue or cues  $\varphi(T)$  to the relevant patterns in the stored knowledge on operation is triggered and the workable scheme  $h(T)$  is chosen and collections in the working memory are updated. Accordingly decisions are made and action is carried out.

### **5.2.2 Agent model of a driver's cognition with naive mental model of a support system**

By providing the advanced assistance systems on-board, the engaging/disengaging and enabling/disabling of driver's mental models have been tried to make appropriate for normal as well as time critical situations. The support systems direct the driver to engage the required mental models to actively allocate the attention to the specific environmental/vehicular condition and help them take prompt actions. However, adequate engaging/disengaging and enabling/disabling via automation also requires the driver's mental models to include the knowledge of its assistance capacities and the respective demands of interaction.

If the KB mental models about the automation are prejudiced due to the limited information on its functionality; then the driver may tend to engage the relevant mental models for a situation only at the time of information displayed by the system about it. Otherwise the needed mental models might be kept disengaged and disabled with the notion that automation is also monitoring the environment for the driver. The partial KB mental models can encourage the driver make this a simple rule that he/she would always be warned or assisted whenever the triggering situation for the system would exist, and there is no need to check automation status intermittently. The driver can relax the attention allocation to the situation for which he/she has the assistance system.

Driver can save this information as a familiar state  $S$  in the memory and have set decisions and actions for it. Whenever the automation would display information, the mental models would be engaged to identify it for a situation and enabled to execute the decided actions, as shown by black solid arrows in Fig. 5.3. Based on naïve KB mental models, the driver might not be able to perceive and distinguish the triggering satisfying conditions for the system, e.g., vehicle speed threshold, weather conditions, road shapes etc., under the influence of which the system cannot issue any warning.

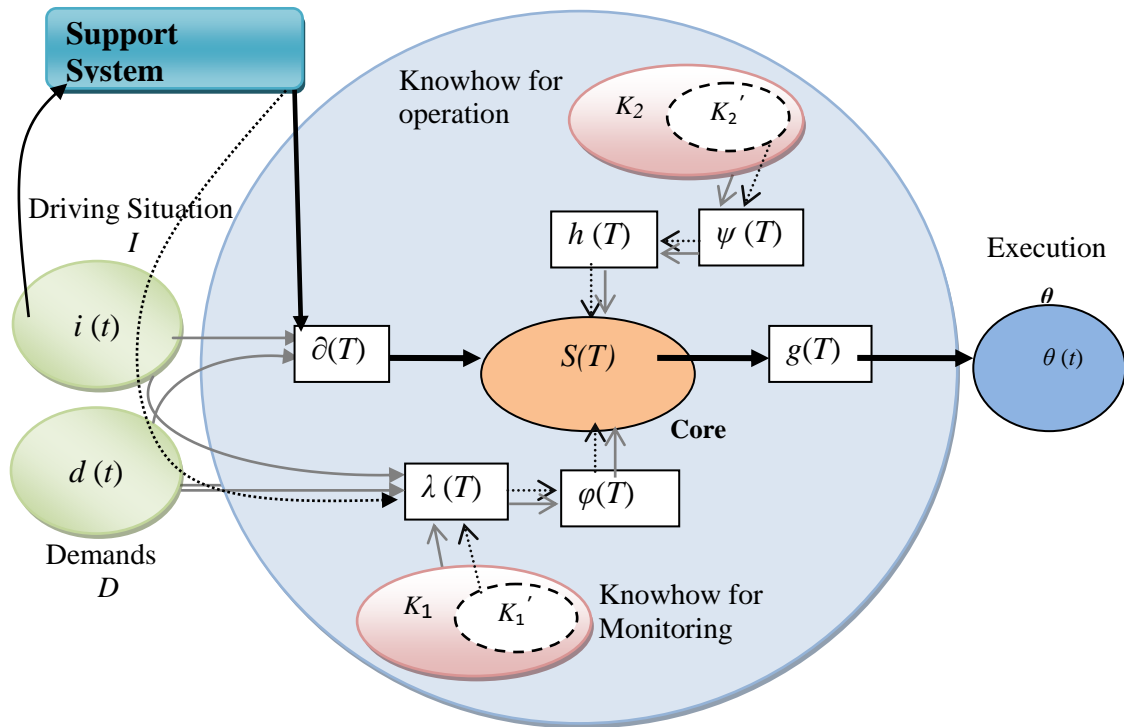


Figure 5.3: Agent model of a naive user's cognition cycle in situations he has a Support System

The only stored familiar state could make the driver depend on the system to alert him/her. Due to the deficiency in driver's knowhow storage, depicted by empty circles of  $K_1'$  and  $K_2'$  in Fig.5.3, on monitoring and working of the system, the links between the states and the functions in the cognition cycle corresponding to the system state get broken; shown by dotted arrows in Fig. 5.3. Thus, in anomalous circumstances the driver becomes unable to do any state interpretation, recommendation, matching and decision making in accordance to the system. This type of behavior, which has its foundations on self-made rules, also inherits the tendency to become a skill-based behavior.

Although the human driver keeps on gathering the information from the

environment as well, but due to his understanding of the system's operation his environment scanning activity, information interpretation etc., becomes passive in the situations for which he has the assisting system as shown by grey arrows in Fig. 5.3. If a situation gets out of the capacities of a system, the driver contingent upon his mental model might not extricate it as in the core no such state be present. The cognition cycle gets impaired, which leads to complacency and even delays learning from experience. "No information-No Action" could then be a part of the practice unless something goes really wrong from routine. Somehow, if the driver becomes able to notice that the system is not issuing any warning or is not taking any action (in case of higher level of automation) in the situation it should have, even then due to the limited knowledge he/she would not be capable of comprehending its behavior. The sequence of events could lead to usability and eventually acceptance issues of the systems by the drivers.

The introduction of new or improved systems usually brings with them the new tasks and the old tasks schemes change or sometimes even disappear (Hollnagel and Woods, 2005). But if something goes different during new interaction, users having partial mental models often do not critically investigate it and accordingly update themselves. Rather, they persistently try to fix it by fitting data to their existing models and disregard any information that is not coherent with their expectations (Norman, 2007). That is why training in pattern recognition and pattern matching for prompt skill accumulation is highly recommended (Stanton et al., 2001; Gaba et al., 1995).

Thus, in the presented work the broken links in the cognition cycle of a naive user have been tried to reconnect through the provision of on-board quick guidance, via visual display, on system operational limitations in particular driving situations. It is believed that by taking precautionary information out from manuals and providing it inside the cars would enhance Driver-Advanced Assisting System Interaction and overall safety.

## **5.3 Experiments**

### **5.3.1 Apparatus**

PreScan® software version 6.3, was used for ADAS simulation in this study. Figure 5.4 presents the setup of the driving simulation. All the things were same as before; however a small display screen connected with the laptop computer running MATLAB was added for displaying information regarding design boundaries of LDW system to guide subjects

when they were driving a simulated vehicle. It was used as a copy of multi-information displays in real cars and accelerator pedal, with automatic gearshift. The steering wheel could provide haptic feedback.



Figure 5.4: Experimental setup

### 5.3.2 Participants

Thirty-two people (including 5 female), between the ages of 21- 45 years, took part in this study. All participants had a valid driver's license and at least one year of driving experience, but none of the participants had an experience of driving a vehicle equipped with the LDW system. Few participants had heard about this system, so they had a little information about it. However a written document containing general information about the purpose of the system was provided to the participants before the experimental session. The paragraph similar to the first paragraph in the overview of the LDW system was narrated in the written material. This was done to replicate a situation where a driver starts interacting with a new on-board technology while lacking sufficient knowledge about it.

### 5.3.3 Design and procedure



Figure 5.5: Screenshot of first-person view and driving simulator test track

The driving scenarios were created with the perspective to realize the situations in which the drivers can get the opportunities to experience the implemented operational boundaries of the LDW system.

Also present in the simulation were a number of other automated cars, moving at set trajectories to imitate a dynamic traffic situation. The automated cars could change the speeds and lanes. A simulated four-lane highway, the starting point of the experimental driving setting, was produced which towards the end merged into a two-lane winding road environment. Figure 5.5 presents the first-person view and a portion of the driving simulator test track. Road signs were used to alert drivers to speed limits, for traffic and road conditions, and for demarcation of road segments.

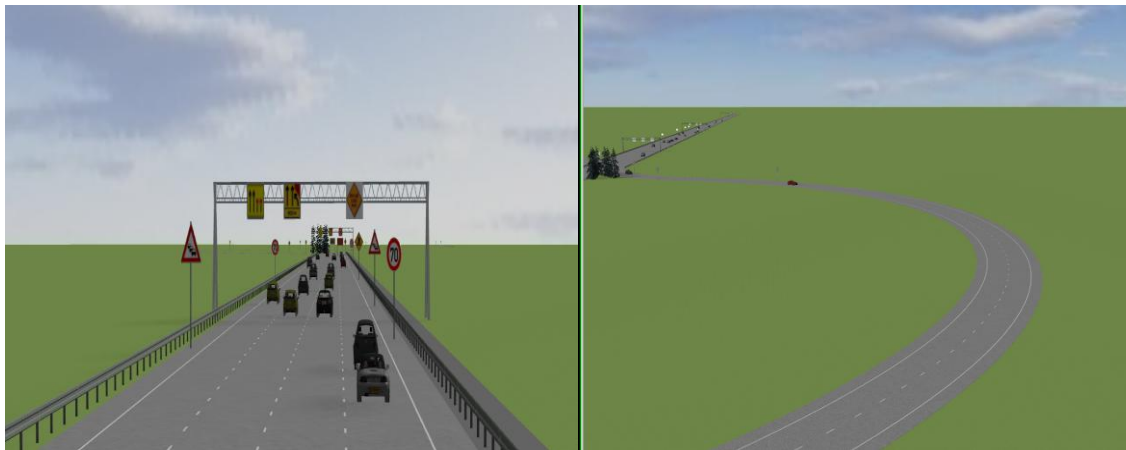


Figure 5.6: Screenshot of car-following driving scenario and the winding road

The initial four-lane highway road had speed limit of 100 km/hr. To introduce the car-following driving conditions, two right-side lanes were closed towards the end of highway and the speed limit was reduced to 70km/hr and then to 50km/hr as shown in Fig. 5.6. At the start of winding road speed limit was 50 km/hr which was further reduced to 40 km/hr because of the more curved nature of the road.

A small graphic area, same as before, located in lower portion of the central monitor screen was used to display speed and present warning text, i.e., “departing left” or “departing right”, indicated as Region A in Fig.5.4. When warnings were issued, the warning text blinked in red. Warning was also simultaneously issued haptically through the steering wheel using rapid vibration. There was no auditory warning.

In our experimental setup, following operational limitations of the LDW system were implemented;

- The Lane Departure Warning system started operating at the speed of 40 km/hr.
- The system could not issue any warning if the distance between the lead car and the host car was small.
- The system was made unable to warn the driver for any lane departure on the winding road. The disability of the system was also illustrated visually through the interface by changing the color of the warning text into orange as shown in Fig. 5.7.
- The system was not working in snow or rainy weather.

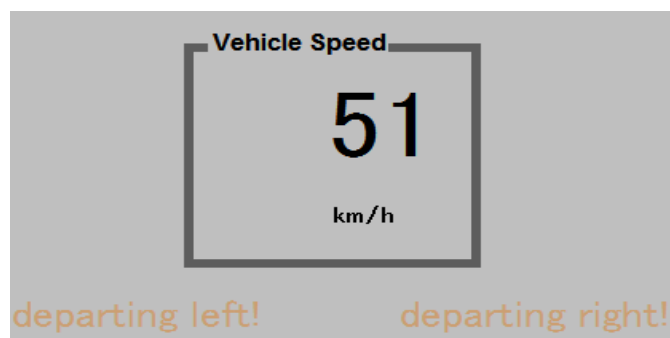


Figure 5.7: Disabled LDW system indicator

One complete experimental session was consisting of three separate trials; **Trial 1**, **Trial 2** and **Trial 3**. During **Trial 1**, the participants had to get acquainted to the employed operational limitations of the LDW system by themselves and there was no precautionary information displayed to them about it. In **Trial 2**, the small screen was introduced as a multi-information display. The precautionary message about the five implemented functional limitations of the LDW system appeared on this small screen at the beginning of the trial. The message was containing concise text and illustrations (taken from Google images) as shown in Fig. 5.8.

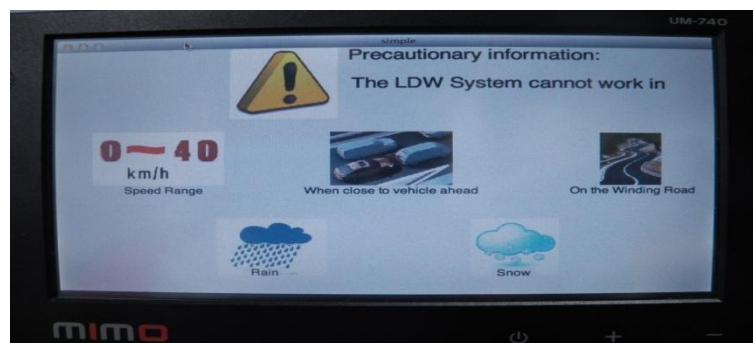


Figure 5.8: Precautionary message on the small screen

The purpose of the **Trial 3** was to evaluate the effectiveness of the event-driven prompted display, illustrated in Fig. 5.13, as a reminder for the out of capacity condition of the system in an ongoing situation.

The content of drivers' mental models about the capacities of the new technology was measured by multiple methods; general questionnaire for concept elicitation and Situation Awareness Global Assessment Technique (SAGAT) to track participants' awareness level of automation and surrounding environment. A set of questionnaires (Appendix II) was prepared to be answered by the participants in each trial during the experimental session.

- The first part of the questionnaire was provided at the beginning of the experiment, which gathered general information about the participant.

The second part of the questionnaire was designed to be presented to the subjects during **Trial 1** in three sub-parts. The simulation activity was briefly halted during the trial at different timings and the question sheets were handed to the subjects to measure their awareness level of the environment and the system. The SAGAT stop timings were standardized among the participants. The second sub-part of the questionnaire in this trial was also having a general question encompassing Yes/ No options to multiple driving scenarios, which drivers may often experience in their daily life. These driving scenarios were including situations which are with in and out of the capacities of the LDW system. The question stated that, "*The LDW system would work properly if*", for example

- |  |                              |                                   |
|--|------------------------------|-----------------------------------|
| (a) There are not proper lane markings on the road | <input type="checkbox"/> Yes | <input type="checkbox"/> No       |
| (b) It starts raining                              | <input type="checkbox"/> Yes | <input type="checkbox"/> No       |
| (c) The road is winding                            | <input type="checkbox"/> Yes | <input type="checkbox"/> No, etc. |

The motive of asking this general question was to comprehend the participant's interpretation and vision of the working of the system

- The third part of the questionnaire was given at the end of **Trial 2**. The questions were asked to ensure that the message was read and understood.
- The last part of the questionnaire was containing questions about the event-driven prompted reminder, as in **Trial 3** rainy weather was introduced in the simulated environment. Also this part was including the questions related to the overall effectiveness of (a) the system, (b) the cautionary message and (c) the event-driven



prompted display.

The participants were informed that one complete experimental session would take approximately 1 hour. However, there is no time restriction to complete a trial and they are free to drive as they normally do, can use any lane depending on the traffic conditions and their ease. They were requested to follow the speed limits as much as possible and to remain vigilant as the other automated cars can change the lane and speed. All participants received an explanation of the general setup and gave informed consent. Once the participants became familiar with the equipment, they completed a practice session during which the LDW system was switched off.

## 5.4 Results and Discussions

### 5.4.1 Trial 1

In **Trial 1** there was no guidance on the operational limitations of the equipped system. Participants were having only general information about the system at this point. This trial had three parts and this scheme was achieved by freezing the simulation during the session on the set time intervals.

#### (a) Part I :

During part I, which lasts for approximately 15 minutes, the simulated environment was having highway 4-lane straight road, a clear weather and smooth traffic conditions. However, the traffic flow was designed with the special perspective of making the drivers encounter the operational limitations of the system as much as possible. The participants were asked at the end of part 1, in addition to other random environmental SA questions, about the two design boundaries of the LDW system, i.e., speed threshold and distance threshold to lead car. The results showed, as illustrated in Fig. 5.9, that

- 23 drivers of 32 could not recognize the speed threshold. According to them, the system was working all the time in the entire speed range of 0-100 km/hr.
- 18 drivers could not distinguish that the system does not issue any warning when the host car is moving close to the vehicle ahead. They were of the opinion that the system always issues warning if the lane boundary is touched/crossed regardless of the distance from the lead vehicle.

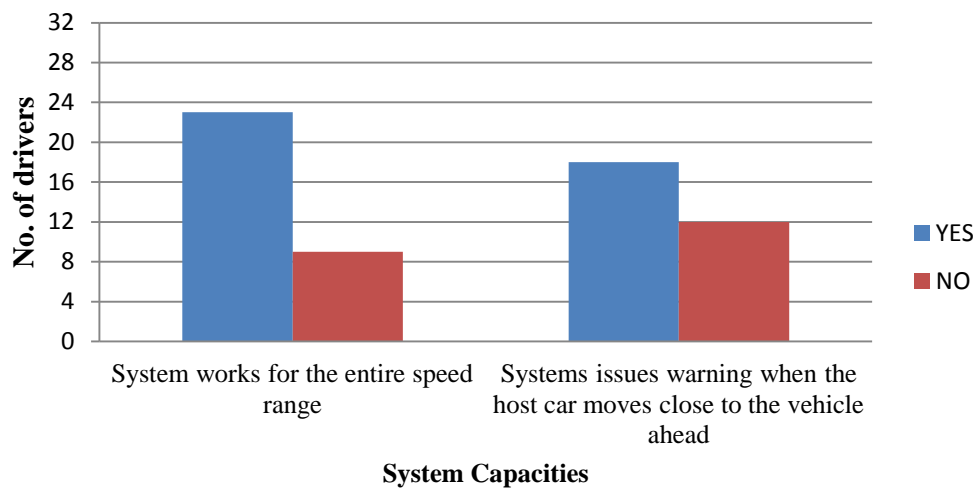


Figure 5.9: Drivers' awareness of design boundaries of the system during Trial 1; Part I

This result helped us to affirm that the mental models most of the drivers owned about the working capacity of the system were very simple, and centered on their expectations to it. To them, the activation of the system and the warning triggering event were independent of any other correlated governing conditions. Since their mental models regarding system did not include its monitoring knowledge, so they could not allocate their attention to observe the system behavior. They answered the questions on the basis of the impression of the system they were having in their mind, even when the system was actually not behaving that way.

The logged data reveal that the 23 drivers who were unable to recognize the LDW system's speed threshold, did touch/cross the lane markings at the speed below 40km/hr. Also 18 drivers, who could not distinguish distance threshold to the lead car experienced lane departures during the car following driving scenario. But they could not notice the absence of the LDW alarm when doing so.

Since in most of the participants' mental model the LDW system was always active and present to alarm them for any lane deviation, they could not keep themselves attentive to the happenings at the speeds below 40km/hr and the operational limitation due to the distance between vehicles. When they did not engage their mental models for the lane departures, they could not learn from experience and ultimately couldn't update their mental models about the LDW system.

**(b) Part II :**

Part II, which was almost 10 minutes long, was basically the extension of Part I to give the drivers further opportunity to experience the system and its operational limitations. The simulated environment remained the same with slight changes in traffic activity. The focus of Part II was not only to lengthen their experience so that they can refine their understanding but also to enquire them about their approach and expectations towards the operational capacities of the system.

It was observed that the number of drivers who could not discriminate the working of the system in relation to the distance to lead vehicle stayed at 18 as before. But the number of drivers who were unable to identify the speed threshold of the system reduced from 23 to 21. It was an improvement, though not that much distinguishing. Most of the participants replied to the question regarding their dependency on the system that they very often felt relying on it to alert them of lane deviation.

When the subjects were asked general questions about their viewpoints regarding the operational capacities of the LDW system, the results, as shown in Fig. 5.10, exhibited the following mental trends;

- 28 participants were thinking that the system is capable of working even in rain.
- 20 drivers believed that the system can work on the winding road and the road shape should not be having any effect on the system functionality.
- 31 drivers out of 32 were of the opinion that the system can work or should be functioning properly in dusty wind.

However, for snow, only 11 people said that the system would warn them of the lane deviation.

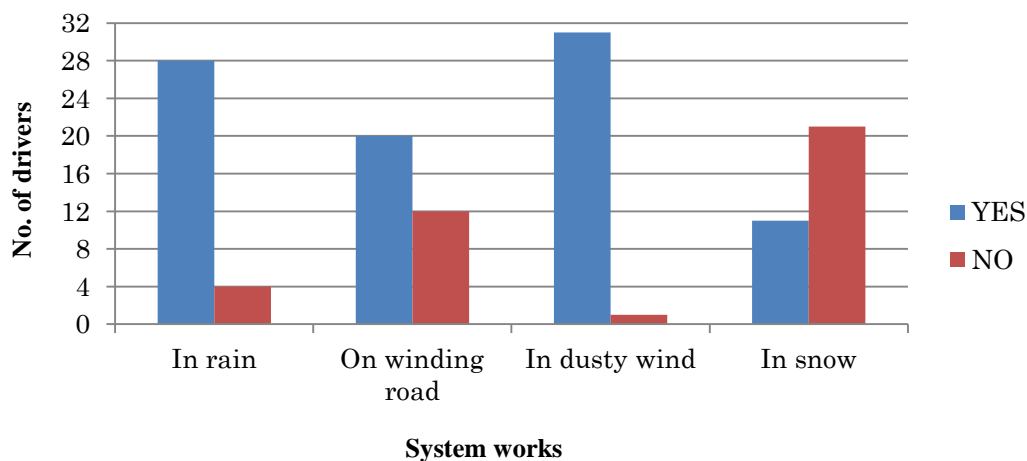


Figure 5.10: Drivers' expectations of the system capacities during Trial 1; Part II

Thus, it would not be wrong to anticipate that the design boundaries of the advanced driver assistance systems might be unexpected to common untrained drivers out there. Because these are the situations in which the drivers need assistance for lane departure the most. Their mental interpretation of the system can influence their situation awareness and consequently driving behavior.

**(c) Part III:**

In Part III, the influence of a driver's mental interpretation of the working of the system in the situation out of its capacities was further explored by introducing a 2-lane winding road in the simulated environment. The system stopped working as soon as the winding road started and the color of the visual warning text changed representing system inactivity, illustrated in Fig.5.7. The duration of this part was almost 15 minutes. When the drivers were questioned and their awareness level of the system activity was tracked, it was found out that;

- During the first 8-10 minutes of driving on the winding road, 20 drivers believed that the system was active. They were depending on the system to alert them and since there was no alarm, they thought that they were driving within the lane markings. They were the same participants who said in Part II that they expect the system to work on the winding road. However, towards the end of the scenario, this number reduced to 8 drivers who kept on thinking that the system was working.
- 18 drivers noticed the change in the color of the warning text, among which only 12 drivers could predict the meaning of this color change.

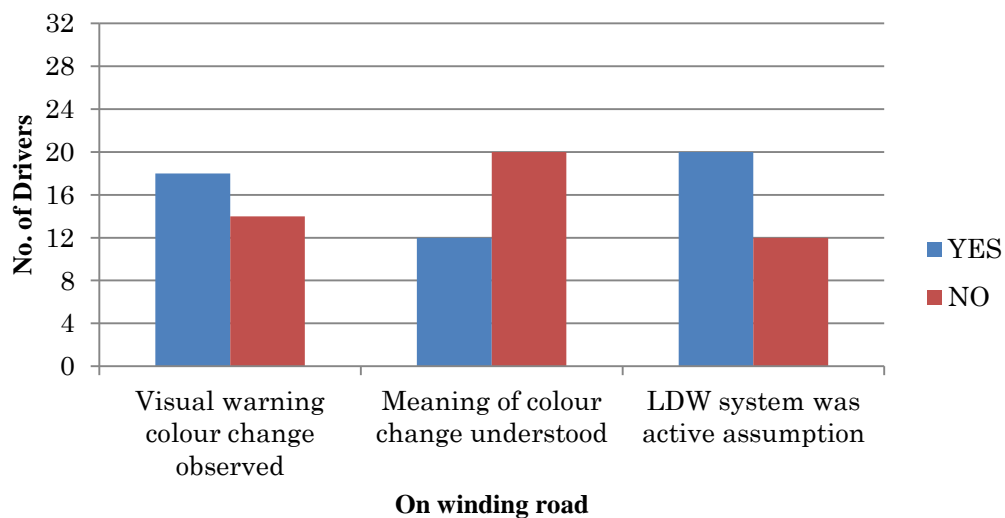


Figure 5.11: Drivers' awareness of the system state during Trial 1; Part III

Figure 5.11 represents the answers of the participants about the system state on the winding road during **Trial 1**, part III. It can be observed that the drivers, who believed that the LDW system can work on the winding road, kept on conceiving the same way and did not notice the inactivity of the system for a while. Although this number reduced from 20 to 8 drivers by the end of the trial, but still did not become a complete 0.

It again authenticates the notion that diverse characteristics and cognitive biasing of the drivers can hold back their mental models from improvement for an unpredictable period of time. We also think that in real winding road driving scenario; the drivers' perception of the system behavior might be influenced more as compared to the simulated environment.

The inattention of the drivers to visual warning can be overlooked to some extent, as in real cars this kind of visual warning is accompanied by an auditory alarm, i.e., beep or a chime sound. However, what is more attention seeking here is the problem of appropriate comprehension of this message by the drivers. It is revealed in the study that a good number of drivers could not understand the meaning of color change of the information display. Thus, the little knowledge of the functional limitations of the system and its illustrations on the interfaces are a threat to overall situation awareness and safety.

Thus, it would not be irrational to say that until this stage of experimental session most of the drivers possessed the cognition cycle presented in Fig.5.3, where gaps exist between states and functions in the cycle in terms of perception and interpretation of system functionality due to cognitive biasing and indeed limited knowledge.

#### 5.4.2 Trial 2

In **Trial 2**, the precautionary message about the chosen operational boundaries of the LDW system was displayed on the small screen, which was imitation of the multi-information display in real cars. The message appeared on the screen and remained there for 12 seconds, just after the commencement of **Trial 2**. The simulation was not paused at any point during the trial and at the end questionnaire was handed to the subjects. The results were quite assuring, as shown in Fig.5.12.

30 drivers understood clearly that what the information was about on the small screen. 26 participants distinguish the states in which the system became inactive, and 24 subjects remembered those states until the end of the trial. The results led us to affirm that on board guidance has a capability to help drivers learn about the system and improve their mental models about it while using it. It was observed that most of the participants

intentionally check the behavior of the system in the available scenarios and they also informed us about this afterwards.

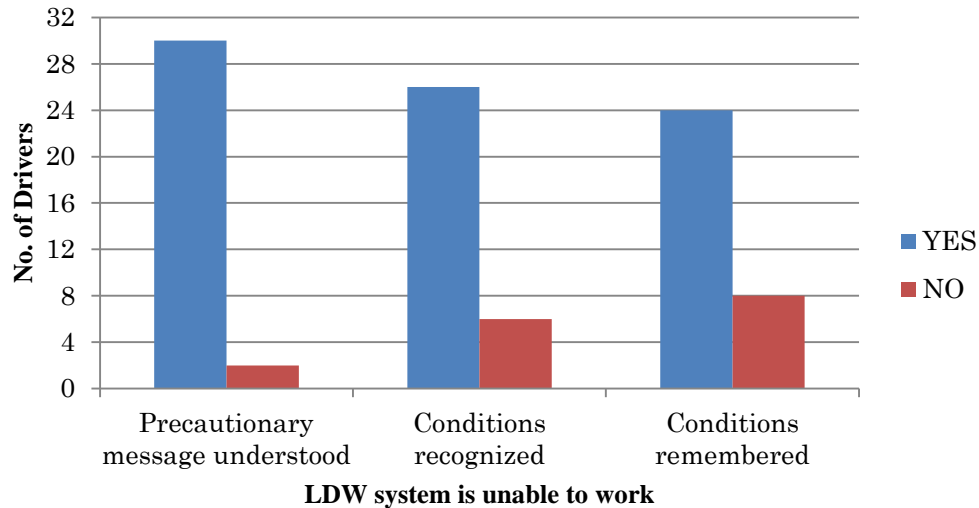


Figure 5.12: Drivers' awareness to precautionary message about the system; Trial 2

Since the timing of precautionary information display or guidance is crucial, so the message was purposely chosen to be shown at the start of the trial. It is also proposed that in real cars too, in order to make the informatory message effective, it should be displayed as soon as the system is engaged by the drivers. At that time a driver can allocate their maximum attention resources to grasp the information being provided.

### 5.4.3 Trial 3

This trial was conducted to evaluate the potentials of event-driven prompted display. The simulated environment was having a rainy driving scenario in this trial.

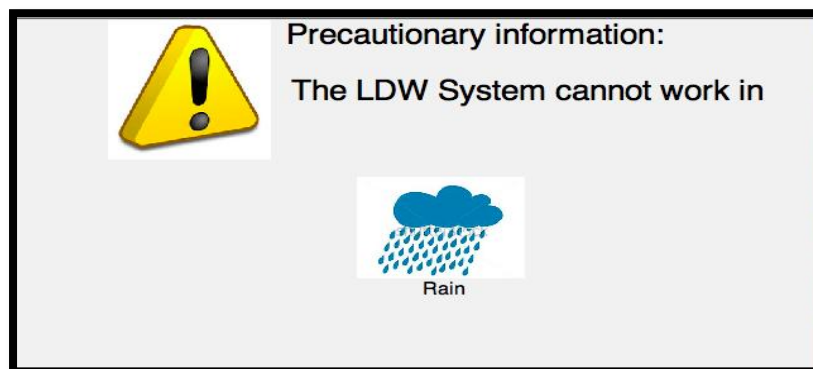


Figure 5.13: Event-driven prompted display

When the trial started, the information was displayed after sometime that the system

cannot work in rain as shown in Fig. 5.13 and then the disability of the LDW system indicator comes up as depicted in Fig.5.7. Then, in the normal driving scenario, the same information again popped up at the start of the winding road.

Most of the participants ranked the effectiveness of this feature high in our scale of the questionnaire, which helped us to deduce that this can be used as a good tool to remind drivers the operational limitations of the advanced driver assistance systems. This could facilitate the driver in staying aware of the system state and reduce their excessive dependency on it.

## 5.5 Mental model improvement

The considerable proportion of the unsuccessful subjects in **Trial 1**, who could not recognize the operational boundaries of the LDW system confirmed that the influence of the partial mental models was so compelling, that it became difficult for them to jump out of false preconceptions by themselves. They experience the operational limitations of the LDW system, but they could not perceive it or learn from it because their impaired mental models did not get engaged to help them observe it. Under the belief of their mental models about the system, for example, it is capable of working at full speed range, they did not monitor it. When they did not engage their mental models to allocate their attention for the system and remained passive observer of the system and the environment, they did not recognize the discrepancies in their mental model and did not make improvements.

The on-board guidance on the functional capacities of the LDW system through visual display had been found to leave a conspicuous impression on participants' cognition. As compared to **Trial 1**, they became more attentive to the system functionality in **Trial 2** and their mental interpretation of its working abilities got reasonably improved.

Participants' correct answers to the questions at the end of Trial 2 not only indicated their upgraded knowledge on the system and their higher awareness of the system, but also affirmed the participants' enhanced recognition of their new role as a 'monitor' of the system. They understood that the system does not always remain active once engaged. They became able to distinguish the driving scenarios where the system might not be able to assist them and the situations where any dependency on the system could be unsafe.

Thus, the broken links in the drivers' cognition cycle got reconnected through

precautionary information display. It helped the drivers to improve their know-how storage on monitoring and operation of the system, represented by merged and added  $K_1'$  and  $K_2'$  in Fig.5.14. The participants' environment scanning activity corresponding to the vehicle position in the lane also became active when they came to know that the system might not be always active. The results showed that on-board provision of knowledge on the system can support the user learn to monitor the system state fluxes in different circumstances, perceive and interpret it in a better way and select the action which is the most pertinent and safe.

Hence, the driver's prejudiced mental models about the capacities of the assisting systems and new coordination demands can be improved using this technique and a satisfactory cognition cycle as shown in Fig. 5.14 can be achieved, even with a naive user.

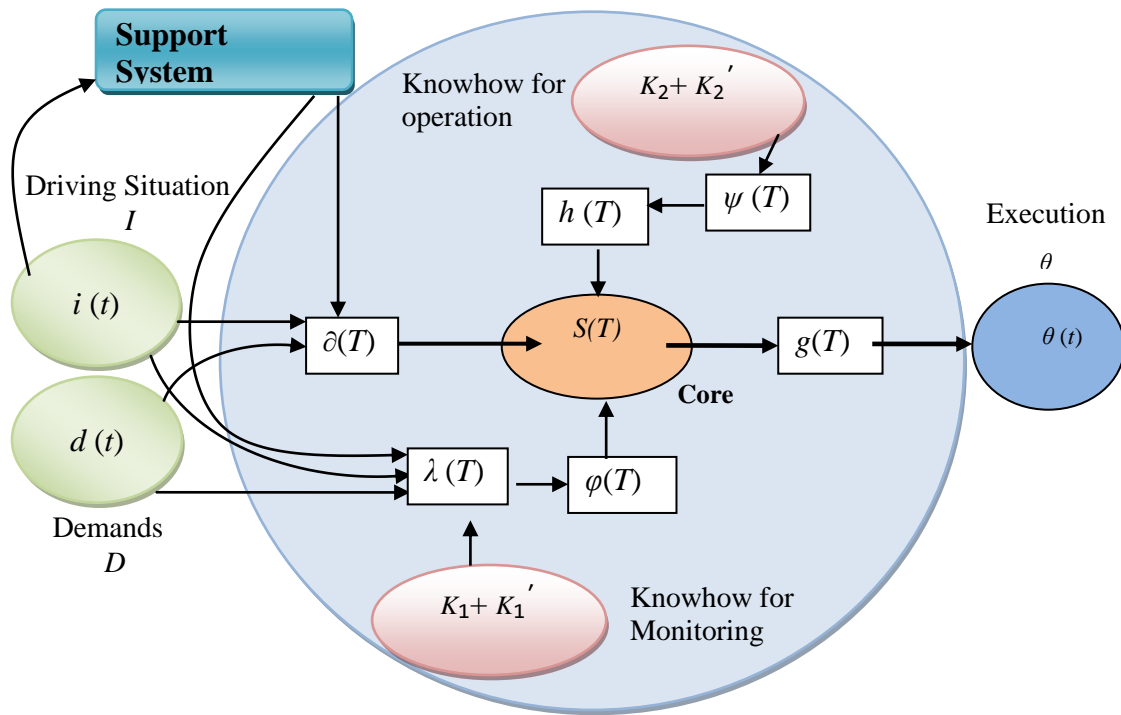


Figure 5.14: Agent Model of a driver's cognition cycle with the support system

## 5.6 Summary

This chapter includes more in detail discussion of the influence of driver's biased mental models about ADAS on their cognitive activity while driving. The conceptual models, elaborating driver's cognition cycle with and without support of automated systems have



been suggested. The analysis of the effects of partial mental models on the driver's cognition cycle has also been carried out.

The former study, explained in chapter 4, has been extended to within-subjects experimental design, employing the same assistance system, i.e., Lane Departure Warning (LDW) System, having more operational boundaries in a driving simulator. To assess the content of drivers' mental models about the new technology more thoroughly general questionnaire for concept elicitation technique and Situation Awareness Global Assessment Technique (SAGAT) method has been implemented. The results have again been found to confirm that the drivers' prejudiced mental models are truly a menace to the benefits associated with ADAS.

To address this issue and to deal with partial mental models of drivers an *on-board quick guidance* on operational limitations of the LDW system through *visual display* as a candidate learning tool has been suggested and employed. The evaluation of the method has shown the encouraging results which has assured the contribution of the proposed approach towards timely construction of driver's adequate mental models. The information directed drivers' attention to the demands of interaction and hence supported their situation awareness and safety.

## 6. Conclusions and Future work

### 6.1 Conclusions

Designing machines to intuitively and efficiently accommodate the limits of the human user have always remained the goal of the engineers and designers. Ever-progressing technology and automated systems advocate this humanity's desire to excel. Along with this, a substantial attention has also been placed to understand that how humans accomplish work-related tasks in the context of human-machine system operation, and how cognitive/noncognitive and behavioral/nonbehavioral variables affect that accomplishment (Wickens and Holland, 1999). It is because that the involvement of human being always stays there with the advanced technical systems in some way. Through this work it has also been tried to contribute to human-automation systems research by focusing on the potential issues in the interaction between driver and ADAS.

ADAS are considerably contributive towards augmenting driver's situation awareness and road safety. Nevertheless if a driver approaches the systems with naïve or prejudiced mental models about it, then the driver's attentiveness to the system's working margins and its assistance capacities remains uncertain. This is again a threat to safety. Driver's interaction with the advanced in-vehicle technologies based on general mental interpretations of its working scheme can induce complacency, weakening overall situation awareness (SA) and judgments. Driver's limited knowledge on the system creates role loopholes, which can precinct their observability and inhibits their learning from

experience. Impaired decision making leads to inadequate driver behavior generation and ultimately reduces safety.

The presented empirical studies have tried to shed light on the need of training of drivers to enable them build and develop functional mental models for the robust interaction with ADAS. The results of the experiments in the studies explicitly showed that most of the drivers were unable to apprehend the operational scheme and capacities of the LDW system, because their mental models about its working were not coherent with it. The results also confirmed that their immature mental interpretations had its origin in their insufficient knowledge of the system, in their irrational expectations to it and in an unawareness of their role as a system operator or supervisor. Thus, in this safety critical task, with the tremendous variety of drivers, the experience based learning of ADAS is not reasonable.

In an attempt to address the above stated issues, it has been proposed that the important information about the design boundaries and capacities of the system should not only be confined to the paper manuals. In the study, it has been observed that an on-board quick and comprehensive guidance on the functional limitations of the system can be a promising instructional tool. The implemented methodology strengthened our idea that the formal teaching techniques or training of the drivers is not the only available solution. Drivers' cognitive biasing about ADAS can be prevented by providing them the opportunities of on-board learning. It is the matter of fact that the assistance, that an automated system provides, can and will lead to reliance or over reliance on it (Wiener and Curry, 1980). However, by providing precautionary information/event-driven prompted display for the operational limitations, this dependency can be reduced to an acceptable and safe level.

Thus;

- To achieve genuine safety and situation awareness with ADAS, and not to replicate the problems of non-functional mental models of other domains here, the availability of the inclusive techniques to make drivers develop appropriate mental models of automation from the commencement is indeed the need of the hour.
- To avoid usability and acceptance issues in driver-advanced assistance system interaction, the informal ways of training and guidance on it could be the workable option.

## 6.2 Future work

It is clear from the research work that the driver's insufficient knowledge and his/her impaired mental models of the advanced assisting systems can undoubtedly influence his/her driving behavior. It is unreasonable to assume that common people would ordinarily learn operational details by themselves, or that the knowledge thus gained would be accurate. As driving automation becomes more sophisticated, the need to reconsider the design and utilization of in-vehicle information systems to improve driver-ADAS interaction becomes increasingly important.

In future research, we hope to explore the proposed method more in depth and with the other assisting systems than LDW system. It is because that in some aspects the operational boundaries of the other systems are a bit more difficult than the LDW system to be presented in a comprehensive way. It would help us to determine how it could be made more smooth and convenient for the drivers to understand and develop accurate mental models of these different systems when they start using them, and how automation surprises can be more effectively avoided.

In future, the study is also expected to extend to multitask and more complex driving scenarios to evaluate the effectiveness of the suggested technique. The prospects and use of recorded speech along with visual display for communicating design boundaries of the system to the driver and evaluating its contribution towards

- decreasing driver mental workload
- assimilating appropriate trust in automation
- mitigating negative behavioral adaptation
- minimizing loss of skills and driver's out-of-loop performance

would also be the objectives of the future research.

---

# Appendix I

## First study questionnaire

**Please fill in the answer that most suits your situation, (Use tick marks in the relevant box).**

If you need more space for any response, feel free to use the additional comment section .

1) Gender:    ☐ Male        ☐ Female

2) Age :        \_\_\_\_\_ years.

3) How long do you have your driving license? \_\_\_\_\_ years.

4) How frequently do you drive a month?

☐ Not so often      ☐ Often      ☐ Very often      ☐ Everyday      ☐ other

Please specify other: \_\_\_\_\_

\_\_\_\_\_

5) Do you prefer to read the manuals or instructions before start using any new device,

system or technology?    ☐ Yes        ☐ No

6) Do you know what is Lane Departure Warning (LDW) system?    ☐ Yes        ☐ No

If 'yes' please state its function in simple words: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

If ' No ' write any ideas that come into your mind about it : \_\_\_\_\_

---

---

7) Did you during the experiment session, at any time doubt the working of the warning system?

- |      |                              |                             |
|------|------------------------------|-----------------------------|
| I.   | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| II.  | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| III. | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| IV.  | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| V.   | <input type="checkbox"/> Yes | <input type="checkbox"/> No |

8) How helpful did you find the lane deviation tool?

- ☐ Not at all      ☐ To some extent useful      ☐ Useful      ☐ Very useful

9) How frequently did you find yourself depending on the warning to alert you of lane deviation?

- ☐ Never      ☐ Often      ☐ Very Often      ☐ Always

10) Have you noticed that at what speed LDW system activates?    ☐ Yes      ☐ No

If ' Yes' please write down: \_\_\_\_\_ km/hr.

If ' No', then write the reason: \_\_\_\_\_

11) Overall, how would you rate the effectiveness of the warning as a tool to maintain safe lane position.

- ☐ Not at all      ☐ Slightly effective      ☐ Effective      ☐ Very Effective.

Additional comments?

---

---

## Appendix II

### Second study questionnaire

**Please fill in the answer that most suits your situation, (Use tick marks in the relevant box).**

以下の問いに答えてください（自分の状況に最も近いものを選んでください）。

If you need more space for any response, please use the additional comment section.

もし書くスペースが足りないようなら、コメント欄・余白を自由に使ってください。

- 1) Gender 性別:    ☐ Male 男        ☐ Female 女
  
- 2) Age 年齢:    \_\_\_\_\_ years 歳.
  
- 3) How long do you have your driving license? 自動車免許を取得してからの年数  
\_\_\_\_\_ years 年.
  
- 4) How frequently do you drive a month? 一か月に自動車を運転する頻度  
☐ Not so often 月に数回    ☐ Often 週 1 回        ☐ Very often 週何回か  
☐ Everyday 毎日    ☐ other その他（以下に記述）

Please specify other:

---

- 5) Do you prefer to read the manuals or instructions before start using any new device, system or technology? 新しい機器やシステム，技術を利用する前に説明書などを読もうと思うほうですか?    ☐ Yes        ☐ No
  
- 6) Based on the provided general information about the Lane departure Warning System (LDW), Please identify the state(s) when the system issues the warning.



車線逸脱警報（Lane Departure Warning: LDW）システムについて提供された一般的な情報に基づいて、システムが警報を発する状態を指定してください（複数選択可）

- ☐ When the vehicle is very closed to/ on the lane markings 車両が車線区分線に接近したとき・車線区分線上のとき
- ☐ When the vehicle crosses the lane markings 車両が車線区分線をまたいだとき
- ☐ When the vehicle deviates from the center of the lane 車両が車線の中央から離れたとき

### **Trial 1: Part I**

- 1) At what speed were you travelling, when the simulation has been paused?  
シミュレーションが停止したときの車両速度はいくらでしたか？  
\_\_\_\_\_
- 2) In the beginning of the experiment session, what was the speed limit written on the traffic sign pole?  
実験開始時、道路標識に書かれていた速度制限はいくらでしたか？  
\_\_\_\_\_
- 3) Where the traffic sign pole was located; on the right side or left side of the road?  
道路標識はどこにありましたか？道路の右側ですか？それとも左側ですか？  
\_\_\_\_\_
- 4) How many cars were there on your right side, when the simulation has been paused?  
シミュレーションが停止したとき、何台の車があなたの右側にいましたか？  
\_\_\_\_\_
- 5) The LDW system is working in the entire speed range of 0~100km/hr.  
LDW システムは車両速度の全範囲（時速 0 ~100 km/h）で作動しています。  

☐ Yes  
はい

☐ No  
いいえ
- 6) In which lane were you travelling when the simulation was paused?  
シミュレーションが停止したとき、どの車線をあなたは走行していましたか  
\_\_\_\_\_

- 7) What is the color of the warning text when the warning takes place?

警報発生時に呈示された文章は何色でしたか？

---

- 8) At any instant while driving, did you doubt the working of the LDW system?

運転中に、LDW システムの動作について疑うことはありましたか？

☐ Yes

はい

☐ No

いいえ

if 'Yes' please state when

「はい」の場合、それはいつですか？

---

- 9) What is the color of the car on your left side, at the instant the simulation was frozen ?

シミュレーションが停止した瞬間にあなたの左側にいた自動車は何色でしたか？

---

- 10) Was it about to rain in the experiment scenario?

今回の実験について雨が降り出しそうでしたか？

☐ Yes

はい

☐ No

いいえ

- 11) If it would have started raining, the LDW system would?

雨が降り始めると、LDW システムは

☐ keep on working. 作動し続ける。

☐ stop working . 停止する。

## **Trial 1: Part II**

- 1) How many times have you changed the lane during this recent session of the experiment?

先程の実験において、あなたは何回車線変更を行いましたか？

---

- 2) In which lane were you travelling when the simulation is frozen?  
シミュレーションが停止したとき、あなたはどの車線を走行していましたか  
\_\_\_\_\_
- 3) At what speed were you travelling?  
あなたはどれくらいの速度で走行していましたか？  
\_\_\_\_\_
- 4) The LDW system keeps on operating whether the speed of the car is low or high?  
車両速度が遅いまたは速い時、LDW システムは作動しつづけますか？  
☐ Yes はい      ☐ No いいえ
- 5) What the traffic sign poles on your left/right side were telling about?  
左側／右側の道路標識は何を指示していましたか？  
\_\_\_\_\_
- 6) Have you doubted the working of the LDW system so far?  
これまでに LDW システムの動作について疑いを持ったことはありますか？  
☐ Yes はい      ☐ No いいえ      if 'Yes' please state when  
「はい」の場合、それはいつですか？  
\_\_\_\_\_
- 7) How frequently did you find yourself depending on the warning to alert you of lane deviation? 車線から逸脱していることを警報によって気付いた場面はどのくらいありましたか？  
☐ Never なかった      ☐ Often あった      ☐ Very Often たくさんあった  
☐ Always 常に警報によって気付いた
- 8) What is the color of the car in front of you before simulation was paused?  
シミュレーションが停止する前にあなたの前にいた車は何色ですか？  
\_\_\_\_\_
- 9) The LDW system does not issue warning, when your car is moving close to the vehicle ahead?  
あなたの車が先行車に近づいているとき、LDW システムは動作していませんでしたか？  
☐ Yes, it does not issue warning.      はい。作動していません。

☐ No, it always issues the warning regardless of the distance from the vehicle a head.

いいえ。先行車からの車間距離によらず、常に作動していました。

10) How many cars were there on your left and right side when simulation was paused?

シミュレーションが停止したとき、あなたの左右に何台の車がいましたか？

---

11) What was the most recent speed limit?

もっとも最近の速度制限はいくらでしたか？

---

12) The information on the highway overhead board was about

高速道路における頭上のボードには、どのような情報が示されていましたか？

- ☐ the weather      天候  
☐ the closed lanes ahead      閉鎖車線  
☐ the speed limit      速度制限

13) Which lanes are closed ahead? どの車線が閉鎖されていますか？

- ☐ two lanes on the right side      右側から 2 車線  
☐ two lanes on the left side.      左側から 2 車線

**Quick General Questions: Please tick the relevant box based on your own opinion.**

簡単な一般的質問：あなた自身の考えに最も近いボックスにチェックを入れて下さい。

The LDW system works properly

LDW システムは

i. If the lane markings on the road are very dim ☐ yes ☐ No

車線区分線が鮮明でないとき

作動する

作動しない

ii. If there are clear lane markings on the road

☐ yes

☐ No

鮮明な車線区分線が存在するとき

- |   |                              |                             |
|---|------------------------------|-----------------------------|
| iii. If the road is straight                        | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| 道路がまっすぐであるとき  |                              |                             |
| iv. If other cars are moving very fast              | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| 他の車両が速い速度で走っているとき                                   |                              |                             |
| v. If the road is winding                           | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| 道路が曲がりくねっているとき                                      |                              |                             |
| vi. If your car is moving very slow                 | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| 自車両が遅い速度で走っているとき                                    |                              |                             |
| vii. If it is too windy                             | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| 風が強いとき  |                              |                             |
| viii. If very small amount of petrol is left behind | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| ガソリンの残量が少ないとき                                       |                              |                             |
| ix. If it is snowing                                | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| 雪が降っているとき   |                              |                             |
| x. If air-conditioner is off                        | <input type="checkbox"/> yes | <input type="checkbox"/> No |
| エアコンがオフのとき  |                              |                             |

### **Trial 1: Part III**

- 1) The traffic sign board "Diversion" was on your left side or right side?

“Diversion” と表示された交通案内板はあなたの右側にありましたか？それとも左側にありましたか？

---

- 2) Why was there the signing of deviation?

どうして “Diversion” という表示があったのでしょうか？

---

- 3) What was the color of the warning text when the simulation has been paused?

シミュレーションが停止したとき、呈示された警告の文章は何色でしたか？

---

- 4) What was the speed limit at the start of the winding road?

曲がりくねった道路が始まったとき、速度制限はいくらでしたか？

---

- 5) What do you think that why the color of the warning text got changed during the last session?

直前のセッションにおいて、警報テキストの色が変化した理由は何だと考えますか？

---

- 6) How frequently did you find yourself depending on the warning to alert you of lane deviation? 車線から逸脱していることを警報によって気付いた場面はどのくらいありましたか？

☐ Never なかった      ☐ Often あった      ☐ Very Often たくさんあった  
☐ Always 常に警報によって気付いた

- 7) The LDW system was working properly on the winding road

LDW システムは曲がりくねった道路で適切に作動していた。

☐ Yes はい      ☐ No いいえ

- 8) While driving on the winding road, at any instant did you think that you were driving safely within your lane on the road and that's why the LDW system was not issuing any warning?

曲がりくねった道路を運転しているとき、あなたは、自車が車線内を走行していたため、LDW システムが何の警報も発しなかったと考えていましたか？

☐ Yes はい      ☐ No いいえ

If 'No', please state why: 「いいえ」の場合、どうしてか教えてください。

---

## Trial 2

- 1) The informatory message that appeared on the small display screen, what was that about?

小さな表示画面上に提示された案内メッセージは、何に関するものでしたか？

---

- 2) At what speed were you travelling, when the simulation has been paused?

シミュレーションが停止したときの車両速度はいくらでしたか？

---

- 3) How many cars were there on your right side, when the simulation has been paused?

シミュレーションが停止したとき、何台の車があなたの右側にいましたか？

---

- 4) The LDW system is working in the entire speed range of 0~100km/hr.

LDW システムは車両速度の全範囲（時速 0 ~100 km/h）で作動しています。

☐ Yes

☐ No

はい

いいえ

- 5) In which lane were you travelling when the simulation was paused?

シミュレーションが停止したとき、どの車線をあなたは走行していましたか？

---

- 6) What is the color of the warning text when the warning takes place?

警報発生時に呈示された文章は何色でしたか？

---

- 7) What is the color of the car in front of you before simulation was paused?

シミュレーションが停止する前にあなたの前にいた車は何色ですか？

---

- 8) The LDW system does not issue warning, when your car is moving close to the vehicle ahead?

あなたの車が先行車に近づいているとき、LDW システムは動作していませんでしたか？

☐ Yes, it does not issue warning.      はい。作動していません。

☐ No, it always issues the warning regardless of the distance from the vehicle a head.

いいえ。先行車からの車間距離によらず、常に作動していました。

- 9) What are those conditions mentioned in the displayed message, in which the LDW system cannot work properly?

表示されたメッセージに述べられていた LDW システムが正しく動作しない条件は何ですか？

---

---

---

---

---

- 10) What was the speed limit at the start of the winding road?

曲がりくねった道路が始まったとき、速度制限はいくらでしたか？

---

- 11) Why did the color of the warning text get changed on the winding road? 曲がりくねった道路で、警告テキストの色が何故変化しましたか？

---

- 12) How helpful did you find the 'precautionary information display' about the LDW system?

LDW システムに関する‘予備情報表示’はどれほど便利だと感じましたか？

☐ Not at all 全く便利だと感じなかった ☐ To some extent useful 一部便利だと感じた

☐ Useful 便利だと感じた ☐ Very useful とても便利だと感じた

### Trial 3

- 1) What were the two conditions for which precautionary information has been displayed?

そのための予備情報が表示された 2 つの条件は何でしたか？

---

---



- 2) How helpful did you find the 'event driven precautionary information display' about the LDW system? LDW システムに関する 'イベント駆動型の予備情報表示' はどれほど便利だと感じましたか？
- ☐ Not at all 全く便利だと感じなかった ☐ To some extent useful 一部便利だと感じた
- ☐ Useful 便利だと感じた ☐ Very useful とても便利だと感じた
- 3) How helpful did you find the lane deviation tool? システムはどれくらい便利だと感じましたか？
- ☐ Not at all 全く便利だと感じなかった ☐ To some extent useful 一部便利だと感じた
- ☐ Useful 便利だと感じた ☐ Very useful とても便利だと感じた
- 4) Overall, how would you rate the effectiveness of the warning as a tool to maintain safe lane position? 以上の結果から，車線内での位置を安全に保つためのものとして，このシステムの有効性をどれくらいだと評価しますか？
- ☐ Not at all 全く有効でない ☐ Slightly effective 少し有効である
- ☐ Effective 有効である ☐ Very Effective 極めて有効である

Additional comments? コメントがあれば書いてください.

---

---

# Appendix III

## Matlab Files

### For introducing LDW system operational limitations:

#### Lane touched/crossed detection\_msfun.m:

```
function LaneChangeDetection_msfun(block)
setup(block);
%endfunction

function setup( block )

%% define number of input and output ports
block.NumInputPorts = 10;
block.NumOutputPorts = 2;

%% port properties
block.InputPort(1).Complexity = 'real'; % Car width
block.InputPort(1).DataTypeId = 0; %real
block.InputPort(1).SamplingMode = 'Sample';

block.InputPort(2).Complexity = 'real'; % Threshold Distance
block.InputPort(2).DataTypeId = 0; %real
block.InputPort(2).SamplingMode = 'Sample';

block.InputPort(3).Complexity = 'real'; % Heading
block.InputPort(3).DataTypeId = 0; %real
block.InputPort(3).SamplingMode = 'Sample';

block.InputPort(4).Complexity = 'real'; % Threshold Angle
block.InputPort(4).DataTypeId = 0; %real
block.InputPort(4).SamplingMode = 'Sample';

block.InputPort(5).Complexity = 'real'; % Distance left
block.InputPort(5).DataTypeId = 0; %real
block.InputPort(5).SamplingMode = 'Sample';

block.InputPort(6).Complexity = 'real'; % Distance right
block.InputPort(6).DataTypeId = 0; %real
block.InputPort(6).SamplingMode = 'Sample';

block.InputPort(7).Complexity = 'real'; % velocity
block.InputPort(7).DataTypeId = 0; %real
block.InputPort(7).SamplingMode = 'Sample';

block.InputPort(8).Complexity = 'real'; % range1
```

```

block.InputPort(8).DataTypeId = 0; %real
block.InputPort(8).SamplingMode = 'Sample';

block.InputPort(9).Complexity = 'real'; % range2
block.InputPort(9).DataTypeId = 0; %real
block.InputPort(9).SamplingMode = 'Sample';

block.InputPort(10).Complexity = 'real'; % distance
block.InputPort(10).DataTypeId = 0; %real
block.InputPort(10).SamplingMode = 'Sample';

block.OutputPort(1).Complexity = 'Real';
block.OutputPort(1).DataTypeId = 8;
block.OutputPort(1).SamplingMode = 'Sample';
block.OutputPort(1).Dimensions = 1;

block.OutputPort(2).Complexity = 'Real';
block.OutputPort(2).DataTypeId = 8;
block.OutputPort(2).SamplingMode = 'Sample';
block.OutputPort(2).Dimensions = 1;

%% Run accelerator on TLC
block.SetAccelRunOnTLC(false)

%% Register methods
block.RegBlockMethod('Outputs', @Output);

%endfunction

function Output(block)
%% init
    car_width = block.InputPort(1).Data;
    threshold_distance = block.InputPort(2).Data;
    heading = block.InputPort(3).Data;
    threshold_angle = block.InputPort(4).Data;
    dist_left = block.InputPort(5).Data;
    dist_right = block.InputPort(6).Data;
    velocity = block.InputPort(7).Data;
    range1 = block.InputPort(8).Data;
    range2 = block.InputPort(9).Data;
    distance = block.InputPort(10).Data;

%% logic
    departing_left = false;
    departing_right = false;

    if (velocity > 40) ;
        if ( range1 <= 7.5)|| (range2 <=7.5)|| distance >= 830 ;
            departing_left = false;
            departing_right = false;
        elseif (((dist_left - threshold_distance) < (car_width / 2)) &&
            (heading < 0)) || (((dist_left - threshold_distance) < (car_width / 2))
            && (heading>=0) && (heading<threshold_angle));
            departing_left = true;
        elseif (((dist_right - threshold_distance) < (car_width / 2))
            && (heading > 0)) || (((dist_right - threshold_distance) < (car_width /
            2)) && (heading>-threshold_angle) && (heading<=0));
            departing_right = true;
        end
    end
end

```

```

        end
    end

```

```

    block.OutputPort(1).Data = departing_left;
    block.OutputPort(2).Data = departing_right;

```

```

%endfunction

```

### **Plot lane departure msfun.m:**

```

function PlotLaneDeparture_msfun(block)
setup(block);
%endfunction

```

```

function setup( block )

```

```

%% define number of input and output ports
block.NumInputPorts = 4;
block.NumOutputPorts = 0;

```

```

%% port properties
block.InputPort(1).Complexity = 'real'; % departing left
block.InputPort(1).DataTypeId = 8; %boolean
block.InputPort(1).SamplingMode = 'Sample';
block.InputPort(1).Dimensions = 1;

```

```

block.InputPort(2).Complexity = 'real'; % departing right
block.InputPort(2).DataTypeId = 8; %boolean
block.InputPort(2).SamplingMode = 'Sample';
block.InputPort(2).Dimensions = 1;

```

```

block.InputPort(3).Complexity = 'real'; % velocity
block.InputPort(3).DataTypeId = 0;
block.InputPort(3).SamplingMode = 'Sample';
block.InputPort(3).Dimensions = 1;

```

```

block.InputPort(4).Complexity = 'real'; % distance
block.InputPort(4).DataTypeId = 0;
block.InputPort(4).SamplingMode = 'Sample';
block.InputPort(4).Dimensions = 1;

```

```

%% register methods
block.RegBlockMethod('PostPropagationSetup', @DoPostPropSetup);
block.RegBlockMethod('Start', @Start);
block.RegBlockMethod('Outputs', @Outputs);
%endfunction

```

```

function DoPostPropSetup( block )
    block.NumDworks = 1;
    block.Dwork(1).Name = 'handles';
    block.Dwork(1).Dimensions = 5;
    block.Dwork(1).DatatypeID = 0;
    block.Dwork(1).Complexity = 'Real';
%endfunction

```

```

function Start(block)
    try
        close (PlotLaneDeparture)
    end
    h_dlg = PlotLaneDeparture;
    h_departing_left = findobj(h_dlg, 'Tag', 'departing_left');
    h_departing_right = findobj(h_dlg, 'Tag', 'departing_right');
    h_velocity = findobj(h_dlg, 'Tag', 'velocity');
    h_distance = findobj(h_dlg, 'Tag', 'distance');
    block.Dwork(1).Data = [h_dlg h_departing_left h_departing_right
        h_velocity h_distance];

%endfunction

function Outputs(block)

    h_departing_left = block.Dwork(1).Data(2);
    h_departing_right = block.Dwork(1).Data(3);
    h_velocity = block.Dwork(1).Data(4);
    h_distance = block.Dwork(1).Data(5);

    set(h_velocity, 'String', num2str(block.InputPort(3).Data));

    color_red = [ 1.0 0 0 ];
    color_gray = [ 0.8 0.8 0.8 ];
    color_orange = [ 1.0 0.8 0.6 ];

    %departing left
    if block.InputPort(1).Data
        set(h_departing_left, 'ForegroundColor', color_red)
    else
        set(h_departing_left, 'ForegroundColor', color_gray)
    end

    %departing right
    if block.InputPort(2).Data
        set(h_departing_right, 'ForegroundColor', color_red)
    else
        set(h_departing_right, 'ForegroundColor', color_gray)
    end

    set(h_distance, 'String', num2str(block.InputPort(4).Data) );

    if (block.InputPort(4).Data) > 830
        set(h_departing_left, 'ForegroundColor', color_orange)
        set(h_departing_right, 'ForegroundColor', color_orange)
    end

%endfunction Outputs

```

### **Multi-information display msfun.m:**

```

function varargout = simple(varargin)
% SIMPLE MATLAB code for simple.fig
% SIMPLE, by itself, creates a new SIMPLE or raises the existing
% singleton*.

```

```

% H = SIMPLE returns the handle to a new SIMPLE or the handle to
% the existing singleton*.
% SIMPLE('CALLBACK',hObject,eventData,handles,...) calls the local
% function named CALLBACK in SIMPLE.M with the given input arguments.
% SIMPLE('Property','Value',...) creates a new SIMPLE or raises the
% existing singleton*. Starting from the left, property value pairs
% are applied to the GUI before simple_OpeningFcn gets called. An
% unrecognized property name or invalid value makes property application
% stop. All inputs are passed to simple_OpeningFcn via varargin.
%
% *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
% instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help simple

% Last Modified by GUIDE v2.5 10-Jun-2013 17:31:18

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',   gui_Singleton, ...
                  'gui_OpeningFcn',   @simple_OpeningFcn, ...
                  'gui_OutputFcn',    @simple_OutputFcn, ...
                  'gui_LayoutFcn',    [], ...
                  'gui_Callback',     []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before simple is made visible.
function simple_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles     structure with handles and user data (see GUIDATA)
% varargin    command line arguments to simple (see VARARGIN)

axes(handles.axes1);
I=imread('warning.gif');
imshow(I);

axes(handles.axes2);
J=imread('rain.gif');
imshow(J);

axes(handles.axes3);
K=imread('snow.gif');
imshow(K);

axes(handles.axes4);

```

```
L=imread('curvy road.gif');
imshow(L);

axes(handles.axes5);
M=imread('speed1.gif');
imshow(M);

axes(handles.axes6);
N=imread('close cars.gif');
imshow(N);

axes(handles.axes8);
P=imread('speed range.gif');
imshow(P);

axes(handles.axes9);
A=imread('close to front.gif');
imshow(A);

axes(handles.axes10);
B=imread('crdz.gif');
imshow(B);

axes(handles.axes11);
C=imread('rain2.gif');
imshow(C);

axes(handles.axes12);
D=imread('snowfall.gif');
imshow(D);

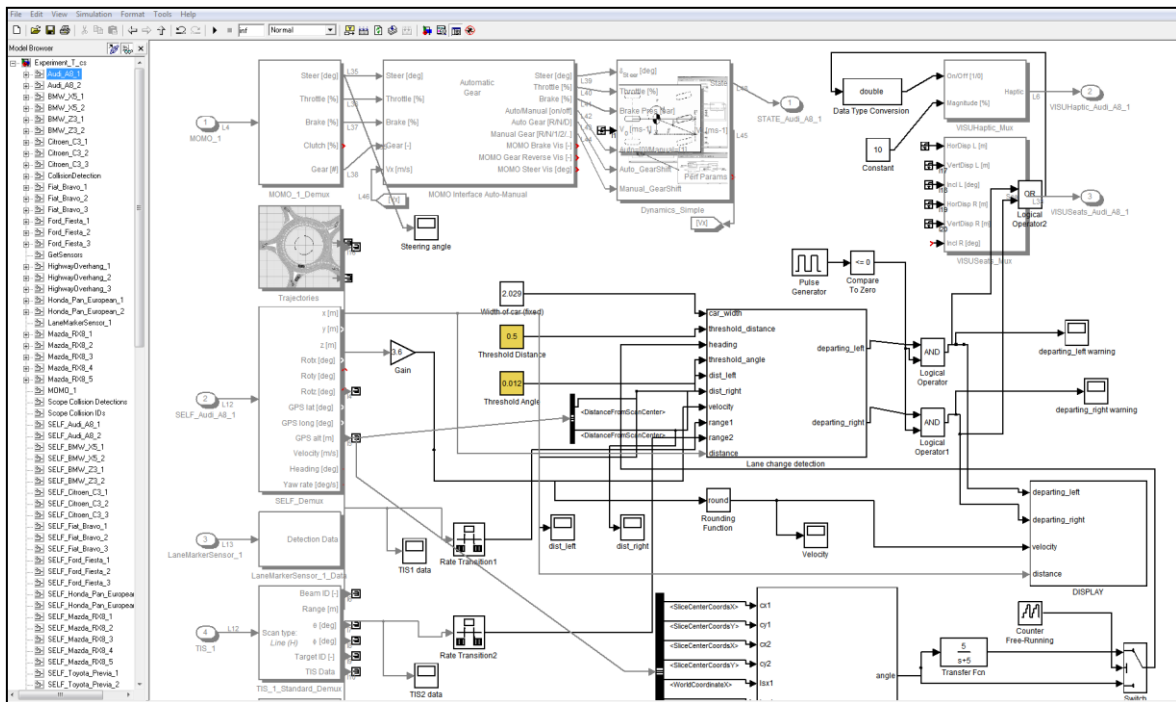
% Choose default command line output for simple
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

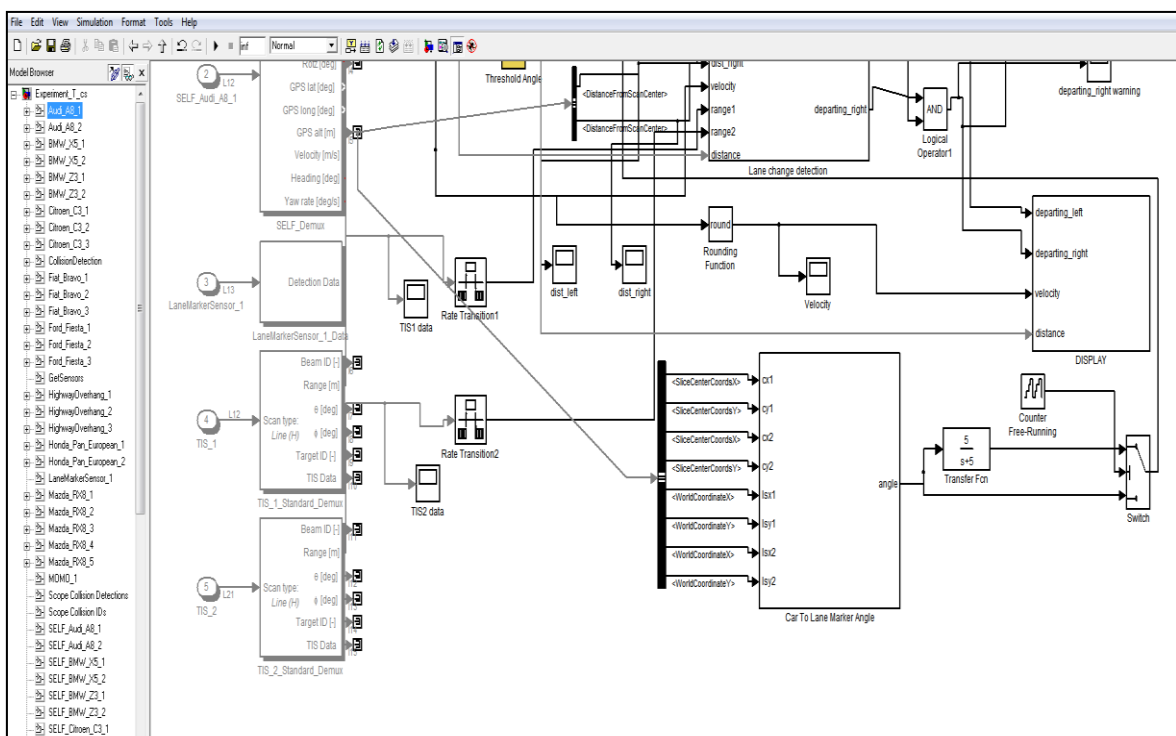
% UIWAIT makes simple wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = simple_OutputFcn(hObject, eventdata, handles)
% varargout cell array for returning output args (see VARARGOUT);
% hObject handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout(Kun et al.) = handles.output;
```

**Simulink window setting:**

Upper half portion of the window



Lower half portion of the window



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# **Publications:**

## **International journal Papers**

- 1) Tabinda Aziz, Yukio Horiguchi, and Tetsuo Sawaragi. Towards understanding the development of driver's mental model of a Lane Departure Warning system while driving. Journal of Advanced Mechanical Design, Systems, and Manufacturing, Vol.8, No.3, 2014. Paper No. 14-00014, [ DOI: 10.1299/jamdsm.2014jamdsm]
- 2) Tabinda Aziz, Tetsuo Sawaragi, and Yukio Horiguchi. Biased mental models and its safety implications on interactions between driver and Advanced Driver Assistance Systems. Applied Ergonomics; submitted.

## **Refereed International Proceedings:**

- 1) Tabinda Aziz, Yukio Horiguchi, and Tetsuo Sawaragi. An empirical investigation of development of driver's mental model of a Lane Departure Warning system while driving. Proceedings of 12th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems, Las Vegas, Nevada, pp. 461-468, DOI 10.3182/20130811-5-US-2037.00022, 2013.
- 2) Tabinda. Aziz, Yukio Horiguchi, and Tetsuo Sawaragi. Role of mental models in interaction with advanced driver assistance systems and its safety implications. Proceedings of SICE Annual Conference, September 14-17, 2013, pp. 1174-1175, 2013.